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TIVENESS OF HIGHWAY ARTERIAL LIGHTING

Final Report

July 1977
Final Report

Prepared for

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Offices of Research & Development
Washington, D.C. 20590

FEDERAL ENERGY ADMINISTRATION
Office of Energy Conservation &
Environment
Washington, D.C. 20461

Foreword

This report describes a new method for evaluating the cost-benefits of urban arterial highway lighting treatments. The safety benefits of a lighting treatment is determined based on driver visibility requirements. Regression equations have been developed to relate the probability of dry weather, nighttime accidents to visibility, population density, and area type. Cost considered in the report include those associated with initial installation, operation, and maintenance of various lighting treatments. The method also allows for trade-offs of energy utilization to be made and provides a framework for rational decision making of conversion of existing lighting systems.

The report presents the results of a study entitled "Effective-ness of Highway Arterial Lighting Treatments" conducted for the Federal Highway Administration, Office of Research, Washington, D.C. under Contract DOT-FH-11-8825. This research was jointly sponsored by the Federal Energy Administration, Office of Energy Conservation and Environment, Washington, D.C. This final report covers the period of research from September 1, 1975 to July 15, 1977.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA Regional office, one copy to each FHWA Division office, and two copies to each State highway agency. Direct distribution is being made to the Division offices.

for *D. Solomon*
Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

This research was undertaken to evaluate the cost-benefits of arterial highway lighting treatments in terms of traffic safety and energy usage. The results have shown that total nighttime dry weather accidents are inversely related to visibility, higher visibility resulting in fewer accidents. Areas with high population densities have a much higher rate than low density areas and CBD areas have a much higher rate than other area types. Regression equations have been developed which predict dry nighttime accident history based on population density, area type and visibility. The results have also shown that more cost-beneficial lighting systems can be designed using HPS rather than Mercury luminaires although it is normally possible to use either source to obtain systems with benefit-cost ratio greater than 1. When visibility and accident reduction potential are the main constraints, optimum designs tend to use 400 HPS luminaires; when cost and energy use are the main constraints, 150 HPS luminaires tend to be optimum.

In addition to this Final Report, a Design Guide (FHWA-RD-77-38) has been prepared to assist potential users in conducting cost-benefit analyses of lighting changes at specific locations.

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PREFACE

The investigations described in this report were conducted by the Transportation Sciences Laboratory of the Franklin Institute Research Laboratories (FIRL) under Federal Highway Administration (FHWA) contract FH-11-8825. Mr. Michael S. Janoff was the Principal Investigator for FIRL, Messrs. Richard Schwab and Paul McMahon were the Program Managers for FHWA. Ms. Shelley Launey was Program Manager for FEA.

This report describes all of the work accomplished during the research contract. It includes the following:

● A literature review covering modern lighting methods, the energy use, costs and benefits of lighting and the relationships between lighting and visibility, traffic operations, safety and crime.

● The design of instrumentation to automatically record visibility data.

● The selection of test sites, field visibility measurements at these sites and determination of accident histories at these sites.

● The analysis of accident and visibility data to develop statistical relationships between visibility and accidents.

● The development of a computer program which can (1) predict visibility based on lighting and road geometry, pavement reflectance characteristics and luminaire distributions and (2) be employed as a user oriented package for designing new lighting systems or upgrading existing systems on arterial streets.

● The development of lighting system costs for modern designs.

● The development of an economic analysis methodology for selecting new or upgraded lighting systems on arterial streets.

● The development of an optimization process which considers costs, energy use, accident or visibility improvements and design limitations as constraints in the selection of new or upgraded lighting systems for arterial streets.

ii

- The determination of the effect of reduced or more efficient use of electric power on visibility and accidents.

- The preparation of a Design Guide which provides the lighting or traffic engineer with a handbook for:

  (1) exercising the VI prediction computer program

  (2) use of the economic/optimization process to design new or upgrade existing arterial lighting systems in urban or suburban areas.

CONTENTS

iv

CONTENTS (Cont)

CONTENTS (Cont)

FIGURES

FIGURES (Cont)

TABLES

TABLES (Cont)

TABLES (Cont)

1. INTRODUCTION AND BACKGROUND

The overall objective of this research was to evaluate the cost effectiveness of several selected urban and suburban highway arterial lighting treatments. Benefits evaluated included those associated with traffic safety and traffic operations. Costs included monies associated with initial installation, conversion of luminaire types, energy usage and maintenance of various lighting treatments. Figure 1 presents an overview of the research program.

1.1 OBJECTIVES

The program was divided into several interrelated parts, and included the following tasks:

1. Reviewed, assimulated and critically evaluated the available literature on highway arterial lighting. These included: roadway lighting methods and specifications; roadway lighting costs, the relationship between roadway lighting and traffic operations, crime and visibility, targets for visibility studies and photometric measurement parameters, and the energy used by roadway lighting systems (A summary of this review is contained in Appendix A).

2. Developed a computer program for predicting the level of visibility provided by fixed highway illumination systems.

3. Selected test sites at which visibility was measured. These sites included examples ranging from best to worst of various illumination levels, light sources, configurations, locations, traffic and pedestrian volumes and roadway configurations. Of primary importance was both an estimate of visibility level (based on lighting and roadway geometry) and night-time accident experiences. The sites selected had at least one years' accident data and included examples ranging from high to low population densities in 3 neighborhood types (Central Business District, Outlying Business District and Residential Fringe).

4. Designed apparatus and developed a methodology for field measurement of the visibility provided by highway arterial lighting systems. Including: illumination, luminance, static and dynamic visibility and their distributions.

5. Collected and analyzed the data to relate visiblity variables to nighttime accident history variables.

1.
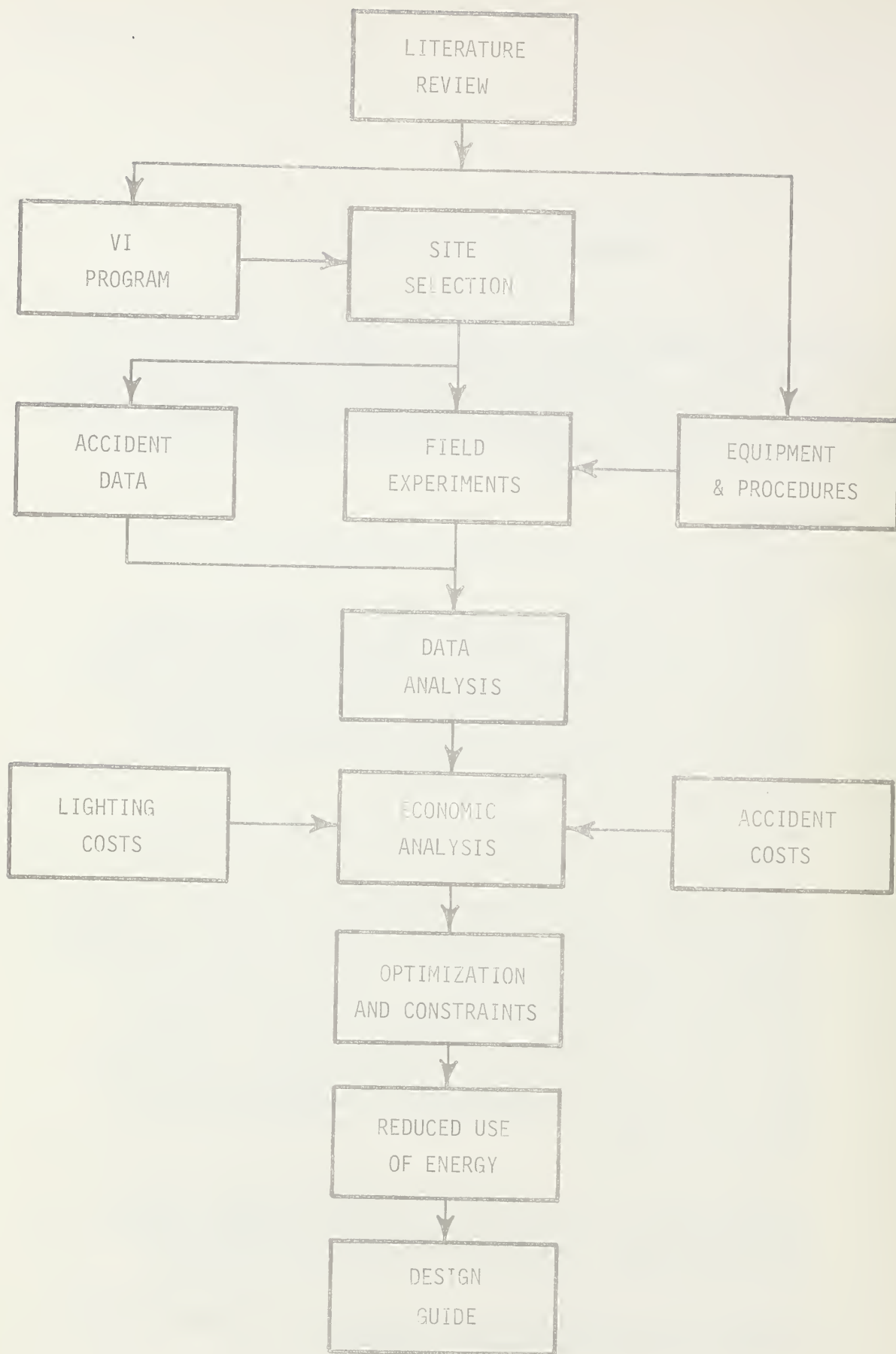
Figure 1. Overview of Research Program

2.

6. Determined typical costs of modern arterial lighting systems – including capital, depreciation, installation, maintenance and operation (energy).

7. Developed a method of economic analysis for determining the effectiveness of arterial lighting systems based on the costs, projected accident reduction, benefit/cost ratios and other traffic flow or esthetic benefits.

8. Developed a method for determining economic/energy tradeoffs in upgrading existing systems to more effective ones – including upgrade costs, energy use (changes), benefit/cost ratios and visibility (changes).

9. Developed a method for determining optimum lighting system designs based on visibility, cost, lighting design and energy constraints.

10. Determined the impact on traffic safety of more efficient or reduced use of electricity for fixed illumination.

11. Developed a practical Design Guide which will assist traffic engineers and highway designers in designing new or upgrading existing lighting systems.

1.2 BACKGROUND

Before reporting on the results of this program, it will be necessary to review two items which are fundamental to the understanding of the research. The first is the concept of visibility and the visibility metric derived by FIRL in past research (1), while the second is a computer program developed under this contract to predict visibility based on lighting design parameters, road geometry and pavement surface reflectance characteristics.

1.2.1 Visibility*

Roadway lighting specifications are typically given as units of average flux with limits on uniformity or dispersion. Warrants are typically related to traffic, geometric and road-use conditions. The specification of lighting has undergone a long history of debate, especially as attempts are made to provide international standards. While there is much disagreement about the efficacy of certain of the warranting criteria, these criteria are generally recognized as being open for discussion and compromise. The fundamental source of disagreement is the

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* See Reference (1) for a more complete discussion of this topic.

3.

question of flux units. Many groups responsible for setting such standards have expressed these requirements in terms of pavement luminance. Since the eye requires reflected light for the detection of objects in space, this approach is clearly related to the needs of drivers. While most scientific studies on the visual requirements of drivers have dealt in similar terms, luminance units present a complex dilemma. The basic problem is that pavement luminance is not yet easily predictable from knowledge of the distribution of flux output by the various luminaires. This is primarily due to the less-than-uniform diffusion of light reflected off paving surfaces.

The human visual-perception mechanism responds subtly to small differences in luminance intensity and exposure duration. It is fundamental that the limitations of this information-processing system must be considered in the context of the human operation under study. It is necessary, therefore, to address this problem in terms of driver information and visibility needs.

In order to determine motorists' visibility needs for the task of detecting an obstacle in the roadways, rigid control of the independent variable (visibility) is required. In addition, a precise method of measuring the responses of a large unbiased sample of motorists is essential.

FIRL developed and installed a variable intensity lighting system on an actual city street in South Philadelphia. The visibility was thus rigidly controllable over an extremely wide range (2).

Field experiments were designed and conducted at this location to determine the time-separation gap at which unalerted motorists responded evasively to a visual problem of known photometric characteristics. The basic hypothesis governing this research was that the time-separation gap characterizing the responses to low visibility targets should be highly constrained and thereby correspondingly shorter than the gap characterizing the responses to a target of higher visibility.

A method of monitoring the vehicle velocity and location was devised that permitted precise tracking of unsuspecting motorists' responses to the visual problem. The responses of over 1300 unalerted drivers under 23 conditions of task visibility were monitored and recorded electronically. The basic performance measure was target intercept time (termed Time-to-Target). This is the time-separation between vehicle and target at the point of an evasive maneuver. Figure 2 illustrates the relationship. Each point in Figure 2 generally represents the mean for about 60 observations for a single condition. The black dots represent negative contrast value, i.e., the targer is brighter than the background; the +'s represent the converse.

4.

The Visibility Index used as a measure of task visibility is determined by the following expression:

$$VI = C(RCS_{Lb}) \times DGF$$

where C = Physical contrast = $\dfrac{Lt - Lb}{Lb}$

         Lt = Target Luminance; Lb = Background luminance

where C = Physical contrast = $\dfrac{\Delta L}{Lb}$

RCS_{Lb} = Relative contrast sensitivity for drivers adapted to a luminance level equal to Lb.

DGF = Disability glare factor

     = $\dfrac{Lb}{Lb'} \times \dfrac{RCS_{Lb'}}{RCS_{Lb}}$

where Lb' = Background luminance (Lb) plus veiling luminance (Lv) divided by a correction for sphere base glare.

The major finding was that drivers' responses to a target, photometrically quantified by the metric described, were predicted with a high degree of accuracy.

1.2.2 Visibility Prediction Computer Program

1.2.2.1 Program Description

The computer program, known as "VI", was originally developed to assist in the evaluation of existing roadway lighting systems on straight roadway sections. The program has undergone several stages of refinement and presently is capable of both evaluation and design of roadway lighting systems.

The VI program calculates horizontal and vertical illumination, (Eh and Ev) and the luminance of a target (Lt) of user specified reflectance, at each point in a roadway grid defined between two adjacent luminaires and both curb lines. For each target point, a driver's position upstream and a background area downstream are defined. Background luminance (Lb) of the roadway area which lies behind the target from a driver's line of sight, and veiling luminance (Lv) produced by each luminaire downstream of the driver are computed for each grid point. The luminance contrast (C), relative contrast sensitivity of the eye to background luminance (RCSLb), relative contrast sensitivity to background plus veiling luminance (RCSLb') a disability glare factor (DGF) and Visibility Index (VI) are calculated for the simulated driver that is

associated with each grid point. The mean, standard deviation and 15th percentile values of the grid array of each of these parameters may also be calculated as an option.

Output may be in either U.S. customary or S.I. units, depending upon input units.

The program may be employed to evaluate existing roadway lighting designs using the conventional parameters of illumination and roadway luminance and more significantly, by using the visual performance measures of glare, contrast and Visibility Index. This is the most direct application of the program. The user must specify the directional candlepower distribution of the luminaire in question, the directional reflectance distribution of the pavement, and the roadway and lighting system dimensions and arrangement characteristics. The relationship of these data to program operations are shown as Inputs (1.) and (2.) in Figure 3. The user may select or suppress the printing of the arrays and/or statistical summaries of any of the calculation parameters by specifying certain output option codes, identified in Input (3.) in Figure 3.

The program may be used as a design tool as well. For any combination of a particular luminance, roadway surface and roadway geometry (width, curb height, crown slope, etc.), the user may indicate a range for variation of system configuration, overhang, spacing and mounting height in Input (3.). The design option program will then generate all system combinations within those ranges and identify each of the design configurations, and their associated photometric and performance measure arrays.

1.2.2.2 Program Operation

The program operates as a series of loops following the input and storage of a luminaire candlepower distribution table and a roadway directional reflectance table. In the Analysis version, the outermost loop takes successive cases from Input (2.) and Input (3.) data. For each case, the program calculates and stores an array of location coordinates for each luminaire in the system. The next inner loop defines a roadway grid, and identifies a driver, target and background location for each grid point. The innermost loop examines each location, one at a time, and calculates and sums the contribution to E_h, E_v, L_t, L_b, L_b' and L_v from each luminaire in the system. When the innermost loop is exited, $RCSL_b$, $RCSL_b'$, DGF, C and VI are calculated and stored for each grid point. When the middle loop is exited, all grid points have been considered and output may be printed. Then, a new case may be read in. The design program works the same way, except that new cases are generated internally as incremental steps of overhang, mounting height, and spacing, and variations in arrangement (single side, both sides-staggered both sides-opposite) and sidedness (near, far, both).
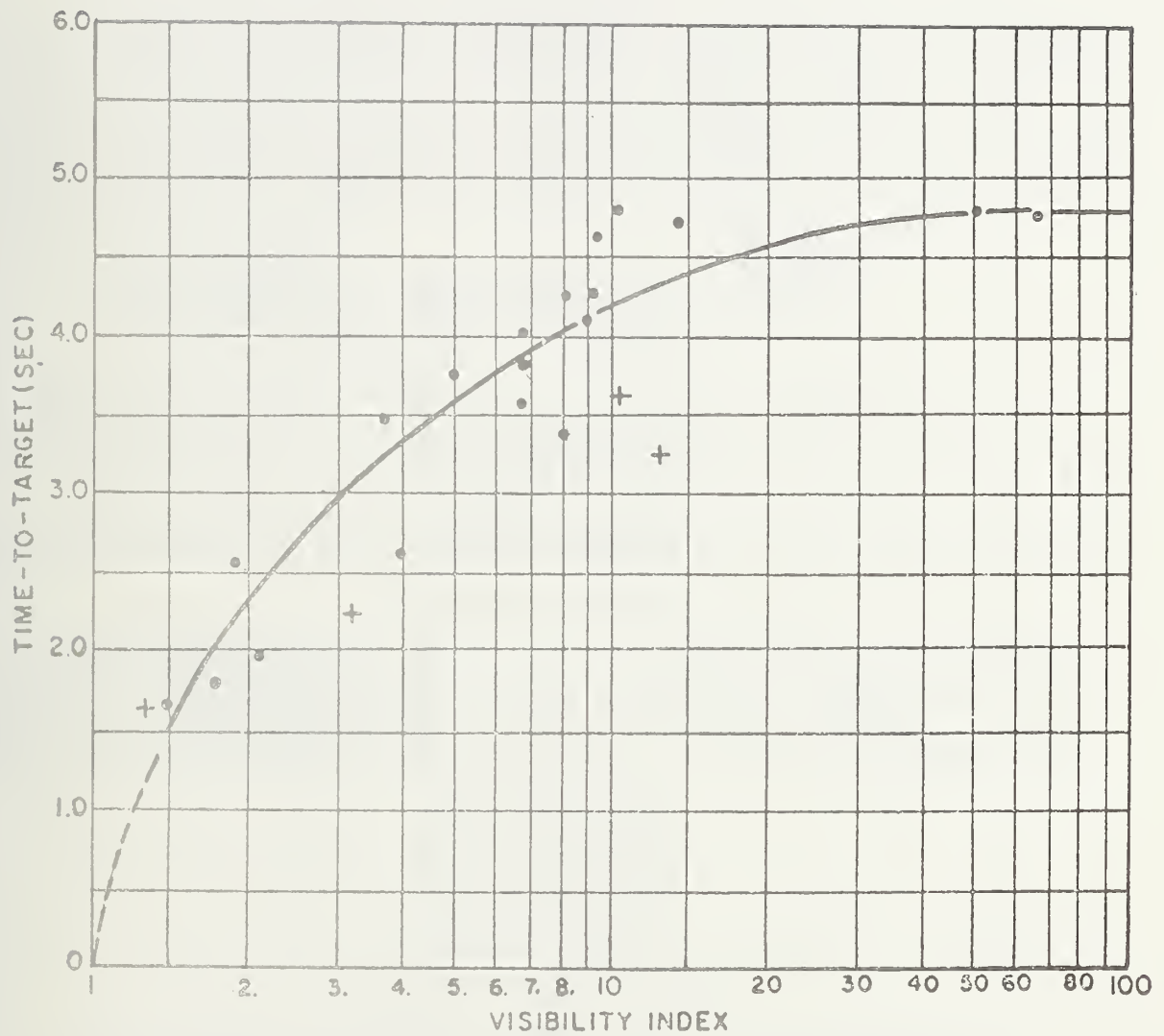
Figure 2. Regression Line for Mean Driver Responses (Raw Data) and Visibility Index

(1.) INPUT

1. Luminaire Candlepower Distribution Table
2. Roadway Reflectance Table

(2.) INPUT

1. Roadway Data
2. Lighting Hardware Data
3. Lighting System Information

(3.) INPUT

Range of Variation of Parameters for Design Program Option

Analysis or Design Option

Analysis Program — Design Program

(4.) ANALYSIS

Analyze A Single Illumination System Design

(5.) DESIGN VARIATIONS

VARY:
1. Configuration
2. Overhang
3. Spacing
4. Mounting Height

(6.) VI CALCULATIONS

Calculate Luminaire Location Array

Calculate Target Position Grid, Background and Observer Information

Calculate E_h, E_v, L_t, L_b, L_b', L_v, RCS_{L_b}, $RCS_{L_b'}$, DGF, C, VI

Analysis or Design Option

Analysis — Design

Calculate Mean, Standard Deviation, 15th Percentile of Each Array

(7.) DESIGN PERFORMANCE MEASURES

Calculate Mean, Standard Deviation, 15th Percentile E_h, VI

Criterion Satisfied

NO / YES

(8) OUTPUT LISTING

Print Performance Measures: E_h, E_v, L_t, L_v, L_b, L_b', RCS_{L_b}, $RCS_{L_b'}$, DGF, C, VI; also Means, Standard Deviations and 15th Percentiles

Other Systems to be Examined

(Other Sites with Same) — YES
(Luminaires and Pavement)
(to be Examined   )

YES — (Design Program to Vary Parameters)

NO

END

Figure 3. Block Diagram of VI Program

8.

The program is organized as a main program, in which the photometric and performance parameters are calculated and five subroutines. The subroutines perform the functions of interpolation for candlepower and roadway reflectance, statistical calculations for mean, standard deviation and 15th percentile, output, and dump for in-depth analysis and debugging.

1.2.2.3 Validation

The computer program was validated by comparison with field measurements taken on the 7th Street Lighting Test facility in Philadelphia[2]. This facility is an isolated city block on which the input voltage, arrangement and sidedness of the lighted luminaires may be varied. Photometric measurements of Lt, Lb, Lv and Eh were conducted for three lighting configurations, using freshly cleaned Westinghouse OV 25 luminaires with clear mercury lamps. The configurations were:

1. 111 ft. (33.84m) spacing, both sides, opposite
2. 111 ft. (33.84m) spacing, single side, near
3. 222 ft. (67.68m) spacing, single side, near

A sample of the roadway surface was shipped to the Transport and Road Research Laboratory, Crowthorne, Berkshire, U.K., where the sample was goniometered and a table of directional reflectance factors were produced.

Comparison of computer predicted to measured parameters indicated acceptable levels of error, averaging 11% for Lt, 7% for Lb, and 12% for Lv.

The remainder of this report is organized into two main sections: the final report (FHWA-RD-77-38) covering all research conducted and the Design Guide (FHWA-RD-77-38), which is provided as a self contained document, and which describes the use of the VI program and the methodology for selecting lighting on arterial streets.

2. SITE SELECTION

The next 3 sections of this report all deal with the field portion of the research. This section includes the selection of test sites, with the aid of a computer program to predict driver visibility (VI) based on road and lighting geometry; section 3 describes the field photometric instruments for measuring VI, the visibility target and the data collection and reduction; and section 4 describes the accident analysis.

2.1 OBJECTIVES

The primary objective of the field portion was to evaluate the visibility existing on a wide range of arterial streets and relate this to the accident experience in these same streets. A preliminary list of approximately 350 sites with various lighting, road geometry area types and population densities was tabulated using the form illustrated in Figure 4. All sites were in the Philadelphia Metropolitan Area and included incandescent, mercury vapor and high pressure sodium lamps; staggered, opposite and one sided configurations; various spacings, arm lengths, mounting heights and luminaire types (e.g., open and closed).

The geometrics of each site were distinctive for a minimum of 6 city blocks. This included the specificity of each sites' road width, direction, road surface type, alinement, number of parking lanes and of course, lighting configuration.

The objective of the site selection methodology was to obtain 81 sites for 27 different experimental classifications - 3 VI levels: high, medium and low; 3 population densities: high, medium and low; and 3 area types: Central Business District (CBD), Outlying Business District (OBD) and Residential Fringe (RF). In order to obtain a VI level for each site the VI computer program was utilized to predict VI15 based on the lighting characteristics, road geometry and pavement surface of each site.

2.2 SITES SELECTED

Using the output of the VI prediction program, potential sites were categorized into low, medium, or high visibility categories according to the following ranges of 15% percentile VI.

<div align="center">

Low   0.0 to 1.99
Medium 2.0 to 3.99
High   4.0 or greater

</div>

SITE CLASSIFICATION

SITE _____ FROM _____ TO _____

TRAFFIC VOLUME: TOTAL _____ NIGHT VOLUME _____

PEDESTRIAN VOLUME: TOTAL _____ NIGHT VOLUME _____

FUNCTIONAL MEAN SPEED _____ SPEED LIMIT _____

POPULATION DENSITY _____ (H-M-L) _____

CBD/OBD/RF _____

TYPE OF LIGHTING: LUMINAIRE _____

                               MOUNTING HEIGHT _____

                               SPACING _____

                               CONFIGURATION _____

                               ARM LENGTH/SETBACK _____

                               DATE OF INSTALLATION _____

GEOMETRY: ROAD WIDTH _____

                 # OF LANES _____ # PARKING LANES____

                 # OF DIRECTIONS _____

                 SURFACE TYPE _____

                 ALINEMENT _____

VI ESTIMATE _____

ESTIMATED DATE OF LIGHTING CHANGE TO HPS _____

Figure 4. Example of Site Classification Form

11.

These categories were derived from the distribution of 15% percentile VI's for all 350 sites.

Population densities in persons per square mile, PPSM, (Persons per Square kilometer, PPSK) for all tracts in the Philadelphia and Chester areas were obtained from the National Planning Data Corporation, from which a weighted population density was calculated since many sites occurred in more than one census tract. A distribution for all population densities was developed and was broken down in the following manner:

        Low   0 - 14,999 PPSM (0 - 5859 PPSK)
        Medium 15,000 - 29,999 PPSM (5860 - 11,719 PPSK)
        High   30,000 or more PPSM (11,720 PPSK)

The neighborhood or area type was characterized as central business district (CBD), outlying business district (OBD) or residential fringe (RF). CBD sites can be described as a high concentration of stores, office buildings, environmental lighting, pedestrian and vehicular traffic as well as parking limited to short periods of time. OBD sites were those areas scattered throughout the city that consisted of shopping centers, clusters of stores, off and on-street parking, environmental lighting and increased vehicular and pedestrian traffic at certain hours of the day. RF sites were those located in the outer portions of the city and consisted of a large concentration of housing with very little environmental lighting and usually the origin and destination of vehicular traffic.

Based on a balanced cross-classification of all three factors, 3 randomly sampled sites were selected for each of the 27 cells. In the initial phases of site selection, many streets in Philadelphia were in the process of being converted to HPS sources so a random selection of all the existing mercury sites could not be performed and subsequently the selection of all possible mercury sites accounted for the three additional sites measured. A complete listing of all 84 sites and their characteristics is found in Appendix B.

3. FIELD EXPERIMENTS - EQUIPMENT AND PROCEDURES

This section describes the development of the target, instrumentation, field equipment and field methodology - including data collection and initial data reduction procedures.

3.1 VISIBILITY TARGET

A unique visibility target was developed for use in conjunction with the photometric visibility measurement apparatus designed for the present research. The primary objective for the target design was that it be sensitive to the local longitudinal and lateral illumination gradients at a given roadway location. This objective stemmed from the requirement that the measured target visibility should reflect those luminance conditions present within a relatively small and precisely specified roadway area. The overall arterial roadway site visibility would thus be quantified as a distribution (longitudinal and lateral) of local visibility gradients.

A review of the relevant visibility research literature (complete text presented in Appendix A) indicated that to meet the primary design objective, the target would have to be relatively small, close to the roadway, lacking any internal contrast or shadows, and present a multi-facetted surface in three dimensions. The ideal target configuration selected was a hemisphere of 7 in. (17.8 cm) nominal diameter mounted on a cylindrical section of the same diameter and height (see Figure 5).

Preliminary attempts at target construction using pre-fabricated styrofoam forms proved unsatisfactory, due primarily to the surface coarseness which prevented easy application of a smoothly painted finish. A more satisfactory prototype target was constructed by lathe-turning a solid wooden block: this procedure also enabled the target to be made in one piece to facilitate contour and surface smoothness. In field tests, a wooden prototype target displayed poor crash survival properties. A latex rubber mold was therefore constructed around a wooden prototype and targets were plaster cast from this mold in a manual process that created a hollow shell identical in surface texture and shape to the prototype. All cast targets were primed with an interior latex white paint to ensure surface sealing. The MAB paint factory in Philadelphia furnished an interior latex paint mixed especially to match the standard Kodak photographic medium grey and to yield a uniform target reflectance of 18%. While this choice of target reflectance was arbitrary, it is an easily reproducible finish and approximates the observed 15th percentile pedestrian clothing reflectance(3). A photograph of the target, front-spot-lighted against a dark background, is presented in Figure 6.

13.
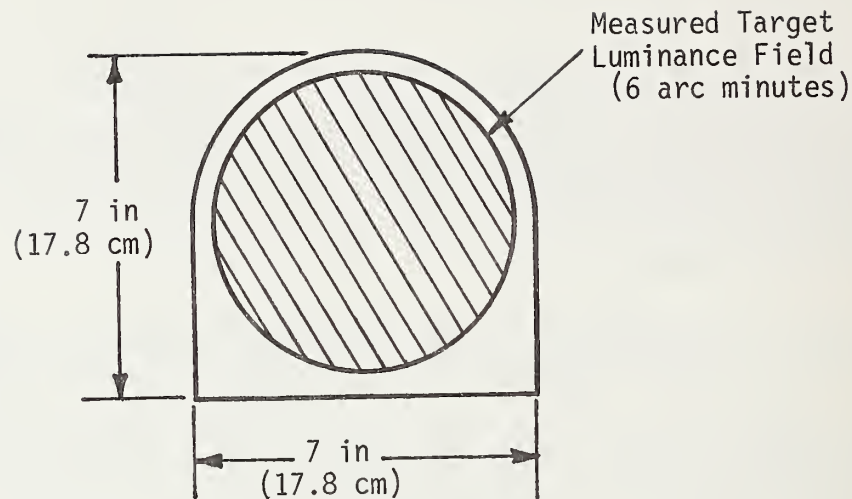
Figure 5. Optimum Target Configuration Showing Position of
Measured Target Luminance Field.

3.2 VISIBILITY APPARATUS

Photometric measurement apparatus was designed to continuously
measure and record target luminance, background luminance, pavement lumi-
nance, veiling luminance, contrast and visibility distributions across
lateral and longitudinal axes of roadway sites. Photometric records are
marked to distinguish ambient (no vehicles present) from non-ambient
(oncoming and same directional vehicles present on the street) periods
of visibility conditions, so that static VI can be determined as well as
the more complex Dynamic Visibility Index (DVI)(3).

Dynamic visibility (DVI), as opposed to static visibility (VI) is a
visibility metric that includes the effect of vehicle traffic on the
visibility index. Its formula is the same as static VI (Section 1.2)
but while static VI is computed under ambient conditions, DVI is the
mean VI during the time when vehicles are present on the street.

The background luminance field against which the target is seen was
measured using a specially fabricated "split-slit" aperture designed at
FIRL. A schematic of the roadway area measured with this aperture and
the location of the target within the measured area is presented in
Figure 7. The perspective view (as seen from the photometers) of the
background field with the target included is presented in Figure 8. The

14.

Figure 6. Picture of Target

split-slit aperture enabled continuous dynamic luminance measurements to
be made without moving or removing the target as in past FIRL visibility
research (3).
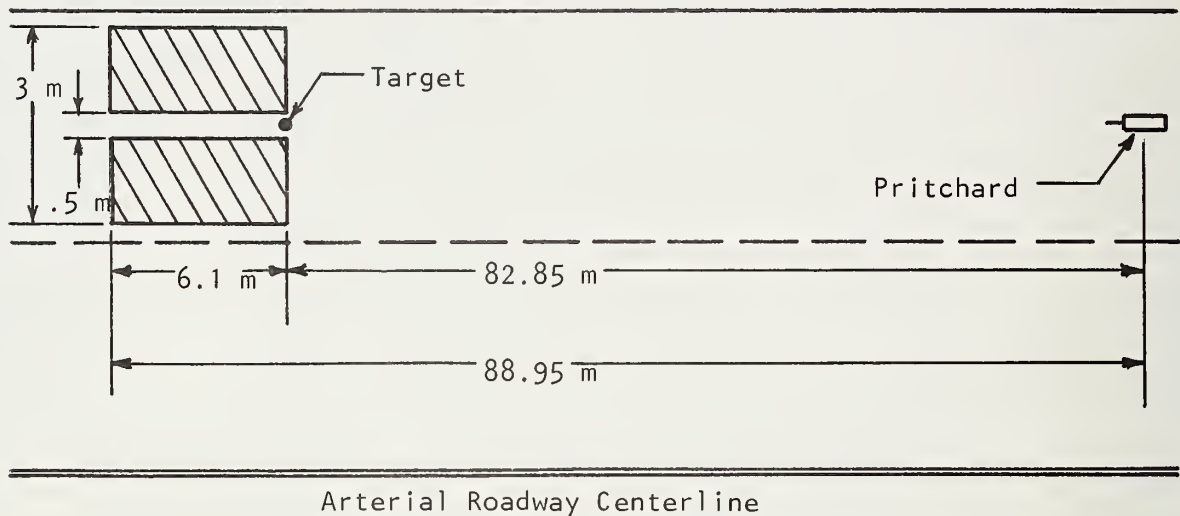
Figure 7. Schematic of Roadway Area (shaded) on Typical Arterial to be
Photometered with "Split-Slit" Aperture. Not to Scale.

The complete instrumentation utilized in the collection of field
photometric measurements at arterial roadway sites consists of a portable
self-powered system contained within the FIRL Traffic Safety Research van.
A schematic of the instrumentation system is presented in Figure 9. The
system is similar to that utilized in past experiments (3), except that
a third Pritchard Photometer is included. All Pritchards are mounted
inside of the truck to facilitate field operation logistics, and the cir-
cuitry provides continuous VI output to minimize the largely manual
analysis required to determine VI and DVI.

A 24 VDC battery pack provides electrical power for field operations
through a 120 VAC inverter. Incorporated within the inverter is a bat-
tery charger, which maintains charge in the battery pack when the system
is not in operation. The regulated power supplies for Pritchards A, B,
and C, the computing circuitry, and the eight-channel brush recorder
rely upon the inverter for 120 VAC power during field operations.

Figure 10 presents a schematic of the computing circuitry needed to
process the target luminance (Lt), background luminance (Lb), and inte-
grating Fry glare luminance (Lf) output signals of the Pritchards. The
instantaneous calculations it performs upon these inputs yields an alge-
braic equivalent of VI of the form
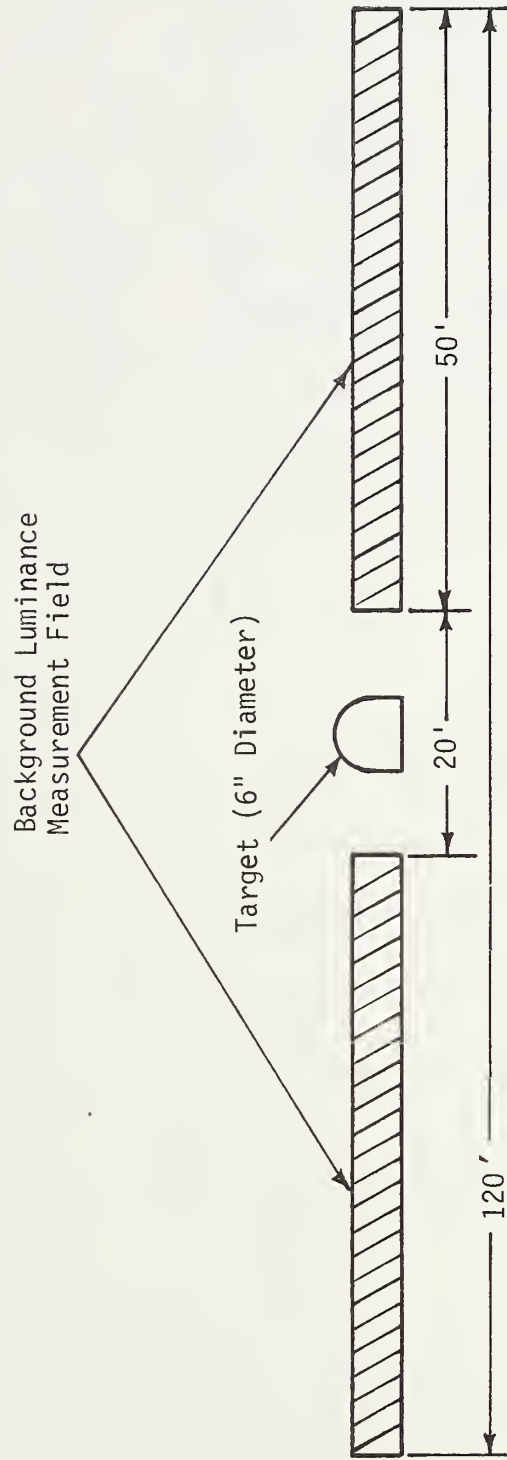
Figure 8. Perspective View (at Photometers) of Measured Background Luminance Field Utilizing Special FIRL "Split-Slit" Aperture, Showing Position of Minimum Size Target.

17.
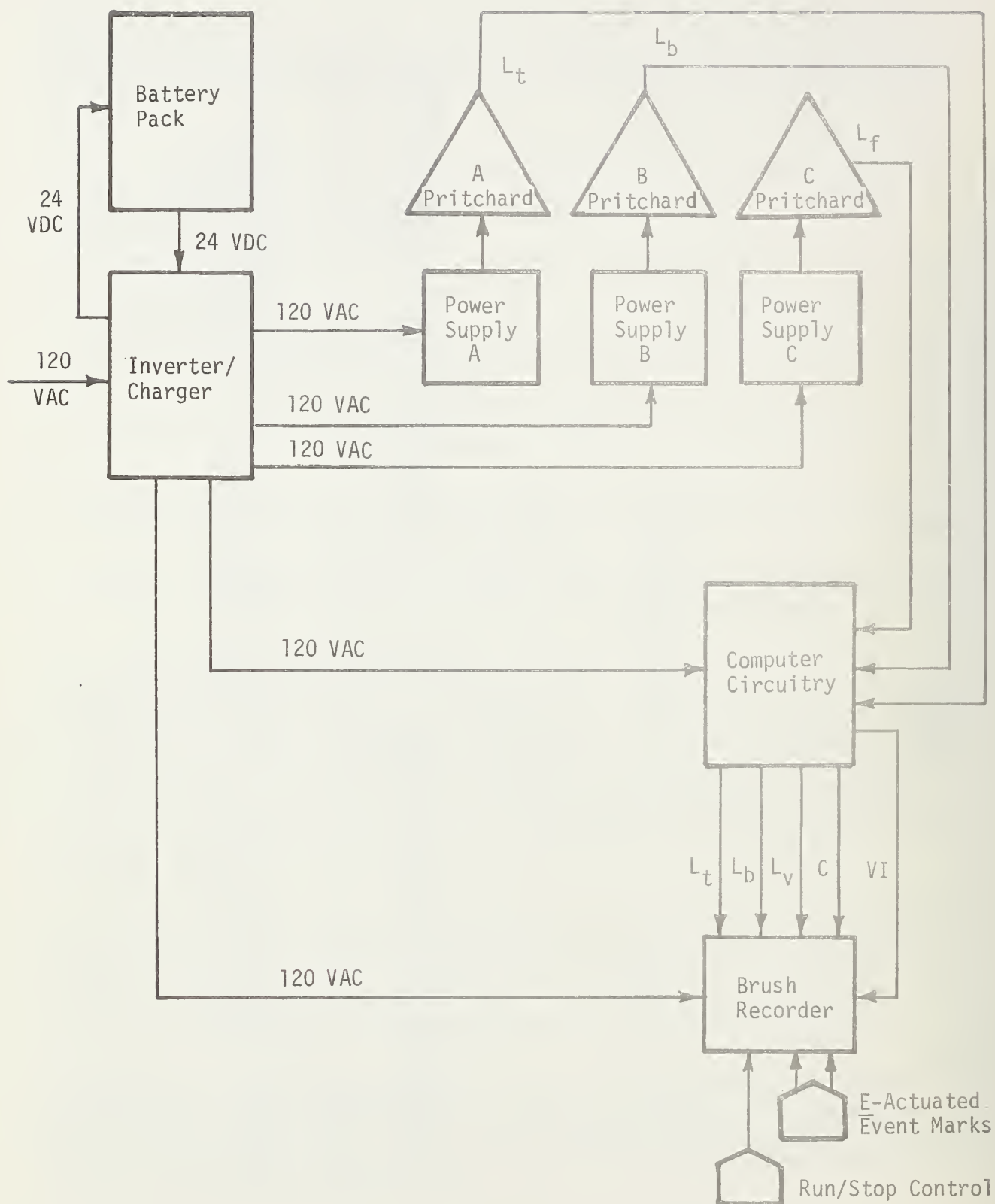
Figure 9.   Schematic of Photometric Measure-
ments Instrumentation.

18.
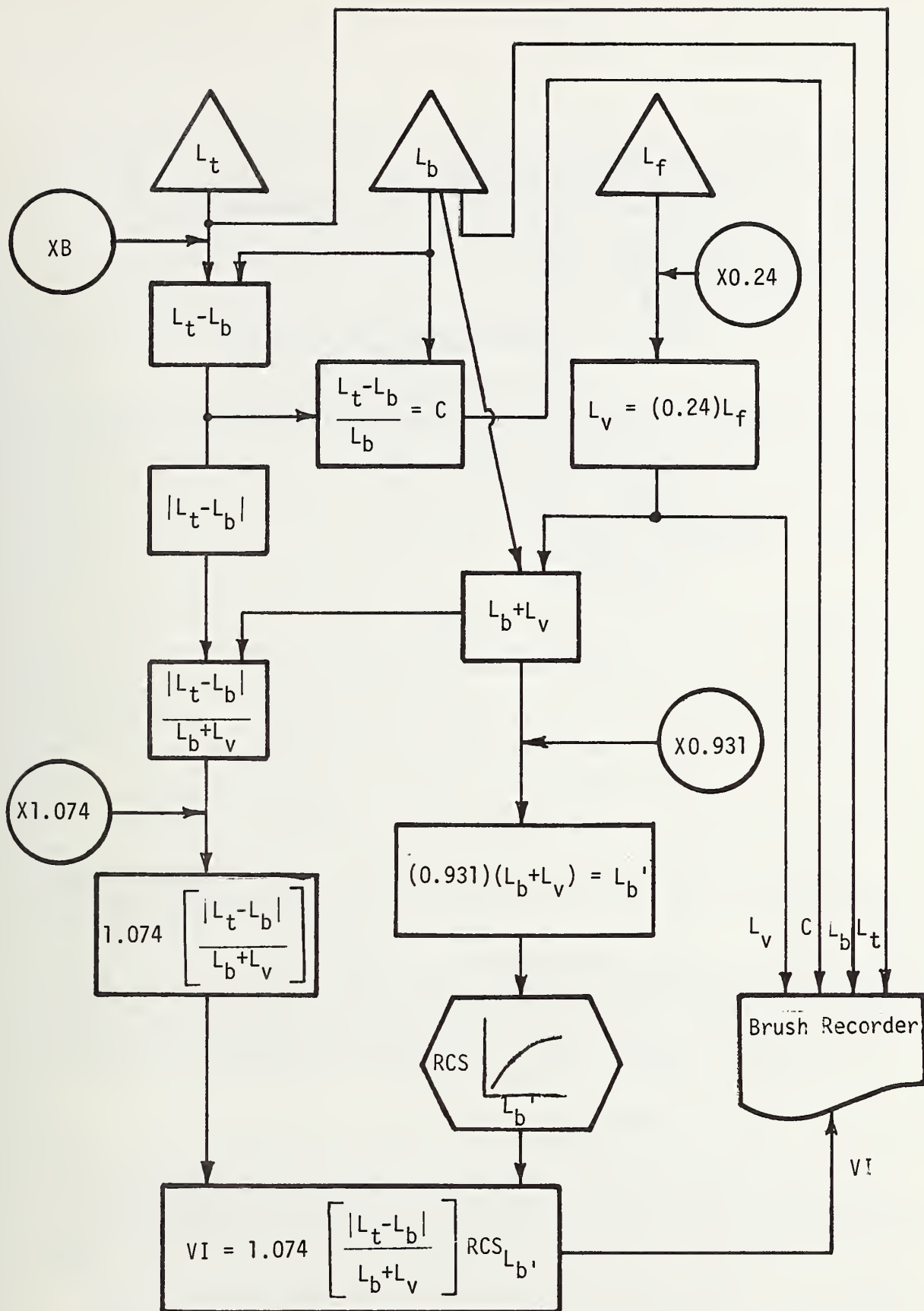
Figure 10. Schematic of VI Computing Circuitry.

$$VI = |C| \ (RCS_{Lb}) \ (DGF) \tag{1}$$

$|C|$ = Absolute value of target luminance contrast

$$|C| = \left| \frac{L_t - L_b}{L_b} \right|$$

L_t = Target luminance (in fL)

L_b = Background luminance (in fL)

RCS_{Lb} = Relative Contrast Sensitivity for drivers adapted to a luminance level equal to measured L_b

DGF = Disability Glare Factor

$$DGF = \left[\frac{L_b}{L_{b'}} \right] \left[\frac{RCS_{Lb'}}{RCS_{Lb}} \right]$$

$$L_{b'} = (L_b + L_v)/1.074$$

L_v = Veiling glare luminance (fl)

L_f = Integrating Fry lens luminance

1.074 = Correction factor for sphere base glare

0.24 = Calibration factor to convert L_f to fL.

In addition to the continuous calculation of VI, the computing circuitry yields outputs of Lt, Lb, Lv, and intermediate C values to be recorded onto the brush recorder. The circuitry also incorporates provisions to manipulate the Lt signal (by multiplier functions) so that VI for other target reflectances can be computed. Other inputs to the brush recorder include experimenter-actuated event markers signifying the passage of oncoming and approaching vehicles and a remote run/stop control enabling the experimenter to record dynamic photometric measurements only when traffic and environmental conditions permit.

3.3 DATA COLLECTION OPERATIONS

For each chosen site, a single block length or more specifically, a single luminaire cycle was selected that showed no peculiarities (e.g., shade trees) which might interfere with the photometric measurements. An extensive physical dimension investigation was made and a scale drawing was constructed which permitted the precise placement of the target positions (TP), Pritchard observation positions (OP) and the C.I.E. trapezoid measurement area (OP trap). While the pritchards and computing circuitry were in the warm-up stage, all TP's and OP's were located and

marked on the roadway in each through traffic lane. An example of:
the schematic utilized for photometric measurements of VI and DVI is pre-
sented in Figure 11 for a typical CBD arterial (Pine Street between 18th
and 19th Streets in Philadelphia). The site is composed of one parking
lane and two through traffic lanes, but Target positions were located
on the centerline of each through traffic lane. The target positions
were spaced at intervals of 20.0 ft. (6.1 m) within the luminaire cycle
that was selected. In the example site shown in Figure 11, the luminaire
spacing was 100 ft. (30.5 m) in a staggered configuration so five target
positions per lane were necessary.

The area within the dotted lines in Figure 11 was that section of
the roadway within the C.I.E. aperture which measured the "mean roadway
luminance" (LTRAP). This static measure was made only once per site and
its primary purpose is to provide a duplicate Lb value which may have
merit as the RCS referent in the VI formulation and as a measure of mean
pavement luminance, used in the statistical analysis. The area repre-
sented in the LTRAP measurement extends from 196.9 ft. (60.0 m) to
524.9 ft. (160 m) conforming to C.I.E. recommendations.

The three Pritchard Photometers are mounted on tripod heads that
were fixed to a platform base in the rear of the FIRL van. This allowed
pan, tilt and elevation in transverse and longitudinal directions. View-
ing height of all pritchards was 4.7 ft. (1.45 m) to approximate the
average height of motorists and pedestrians, and the distance between
the OP and TP locations was the C.I.E. standard of 271.8 ft. (87.8 m)
which yields a vertical viewing angle of 1 degree down from horizontal.

The Pritchard observation parameters included the specialization of
one pritchard each for the measurement of background luminance (Lb),
target luminance (Lt) and veiling luminance (Lv). Lb measurements
employed a specially constructed "split-slit" horizontal aperture as
discussed in Section 3.2.

The target luminance (Lt) measurements were performed utilizing a
circular 6 arc minutes aperture which was centered directly on the target.
Figure 5 depicts the aperture position on the target. All veiling lumi-
nance (Lv) measurements employed the Fry lens with a 2 degree aperture
and was aimed at the target with the aid of a gunsight.

After zero adjustment and sensitivity calibration of all three prit-
chards, the van was moved to OP1 and the target placed on TP1. The dura-
tion of photometric measurements at each TP continued for 100 seconds or
until ambient conditions were obtained. During data recording at each
TP, the experimenter indicated on the brush recorder all approaching and
oncoming vehicles in the field of view as well as the ambient VI condi-
tion.

When sufficient photometric data was collected at the first target
position, the target was moved to TP2, the truck moved to OP2 and the
process repeated. This iteration was continued until all TP's were
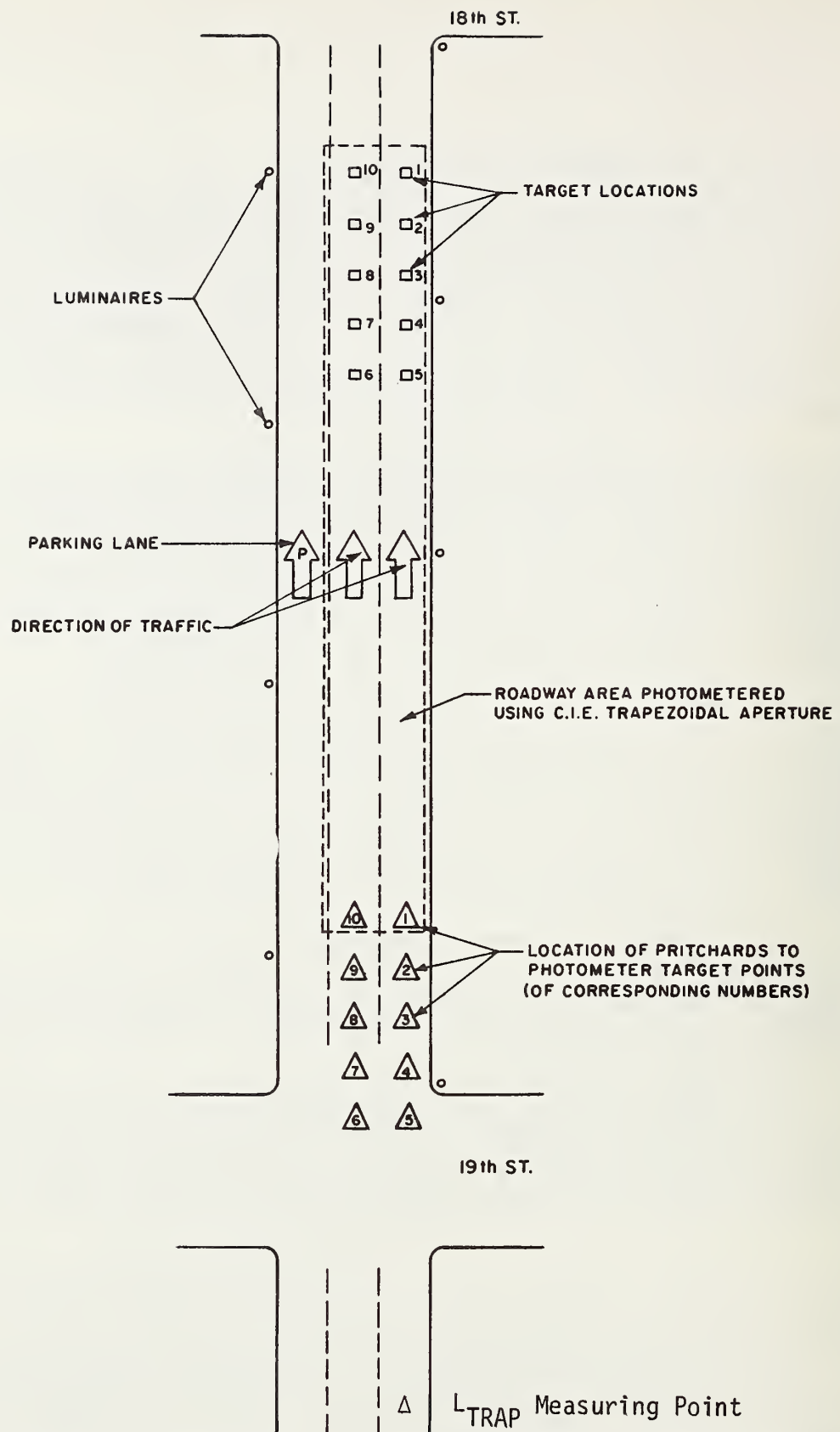
Figure 11.   Schematic of Field Operations at Typical CBD Arterial
(Pine St. between 18th & 19th Sts.). Showing Target
Locations and corresponding Pritchard Locations, C.I.E.
Trapezoid Area and Pritchard Location.

measured. Finally, the van was moved to OP trap, the trapezoid aperture placed in the Lb measuring pritchard and the mean roadway luminance was measured.

After the completion of the luminance measurements, horizontal illumination data was collected by placing the surface of the Spectra Illumination Meter's photosensitive cell parallel to the road surface. The exact points where illumination data was gathered corresponded to the marked TP's where luminance measures were obtained, (i.e., every 20.0 ft. - 6.1 m in the luminaire cycle). These illumination measurements yielded a distribution of values sensitive enough to depict the illumination gradients provided by the fixed lighting.

3.4 DATA REDUCTION

3.4.1 Data Format

All VI data consisted of continuous printed traces from a brush recorder of automatically computed VI for each target position within the measured area of each site. For each VI trace and at every TP, the experimenter indicated VI under ambient conditions which excluded vehicle headlights (approaching and oncoming) traffic signals and cross-traffic within the viewing field. Horizontal illumination was recorded directly from a Spectra Illumination Meter.

3.4.2 VI Ambient Analysis

Ambient VI data was obtained from the printed traces for each TP at every site and subsequently listed on a scale drawing of the particular site. (See Figures 12 & 13). Once tabulated, the mean and standard deviation of the VI distribution values were computed and the mean VI was designated as VI50. The same VI ambient values were then ordered (e.g., smallest to largest) and the minimum 15 percentile VI value for the site was found by interpolation. VI15 can be described as the minimum VI level occurring over 85% of the total measured site area.

3.4.3 DVI Analysis

In comparison to the area basis of analysis for VI ambient data, a time basis of analysis was employed to analyze DVI data by considering the entire 100 second time period from which VI values were obtained.

Analysis of DVI involved a four phase process (See Figures 14, 15 & 16). (1) A frequency distribution was constructed for DVI traces at each TP using intervals of 3 VI units (full scale = 10 units). (2) The DVI interval where the VI ambient existed was eliminated (by consulting the VI ambient map) which produced a new sample size smaller than 100 seconds of non-ambient DVI time. (3) Taking all the DVI frequency distributions for all TP's within the site, a master site DVI frequency distribution was constructed by adding all interval frequencies and
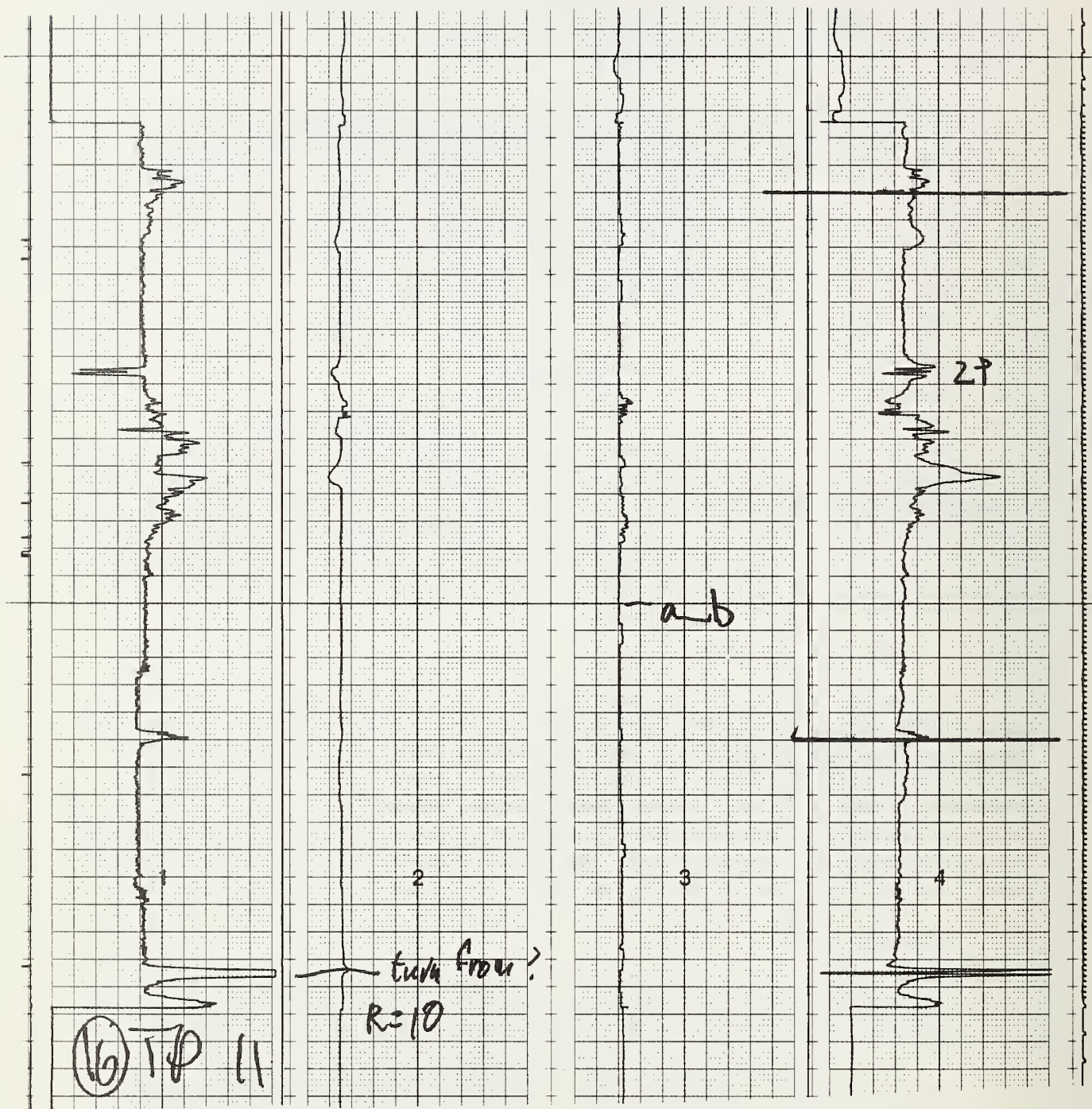
Figure 12. Example VI Trace. Channel 1 is target luminance (L_t) with a
range of 0.0-1.0. Channel 2 is background luminance (L_b) with
a range of 0.0-10.0. Channel 3 is veiling luminance (L^b) with
a range of 0.0-1.0. Channel 4 is the VI trace read on a scale
of 0.0-30.0 from right to left. L_t, L_b, L_v, are all read from
left to right.
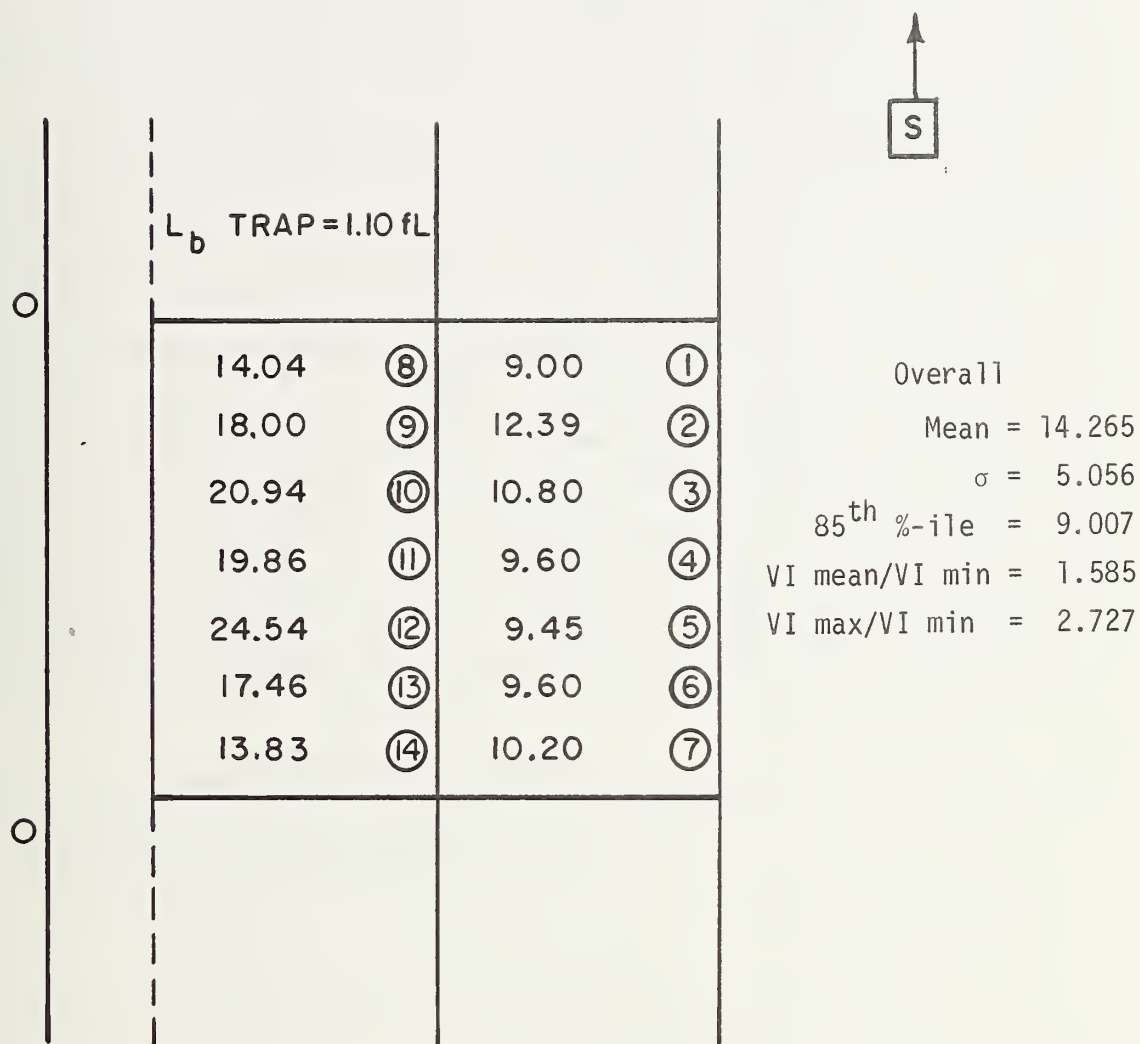
Figure 13. An Example VI Map Constructed From VI
            Traces For Each TP on 21st Street Test Site

25.

ARTERIAL LIGHTING: DVI FREQUENCY DISTRIBUTION

SITE NO. __16__ TP NO. __11__ DIRECTION __N/A__ BY _____

VI UNITS (INTERVAL)	MAJOR DIVISION (0-10 full scale)	NO. SECONDS / VI INTERVAL	CUM SECONDS	INTERVAL MIDPOINT
0- 3.0	1	0	0	1.5
3.0- 6.0	2	0	0	4.5
6.0- 9.0	3	1	1	7.5
9.0-12.0	4	1	2	10.5
12.0-15.0	5	1	3	13.5
15.0-18.0	6	19	22	16.5
18.0-21.0	7	75*	97	19.5
21.0-24.0	8	3	100	22.5
24.0-27.0	9			25.5
27.0-30.0	10			28.5
> 30.0	off scale			31.5

* Interval containing VI_{amb}

Total Non-Ambient time (seconds) = 25

Figure 14. DVI Frequency Distribution Form

NON-AMBIENT
DVI FREQUENCY DISTRIBUTION SITE SUMMARY

SITE NO. 16   TOTAL TP'S 14   TOTAL SECS. 442

VI UNITS (INTERVAL)	MAJ. DIV. (0-10 f.s.)	TOTAL SECS. INTERVAL	INTERVAL PROB.%	CUM. PROB.%	INTERVAL MIDPOINT
0- 3.0	1	46	10.41	10.41	1.5
3.0- 6.0	2	95	22.49	31.90	4.5
6.0- 9.0	3	127	28.73	60.63	7.5
9.0-12.0	4	56	12.67	73.30	10.5
12.0-15.0	5	20	4.52	77.82	13.5
15.0-18.0	6	35	7.92	85.74	16.5
18.0-21.0	7	30	6.79	92.53	19.5
21.0-24.0	8	33	4.47	100.00	22.5
24.0-27.0	9				25.5
27.0-30.0	10				28.5
➤ 30.0	off scale				31.5

85TH %-ILE DVI (BY AREA) = 15TH %-ILE OF DVI DISTRIBUTION = __2.20__

Figure 15. Master Site Form for DVI Frequency Distributions

27.

NON-AMBIENT CUMULATIVE DVI
FREQUENCY DISTRIBUTION

SITE NO. _____16_____ SUMMARY
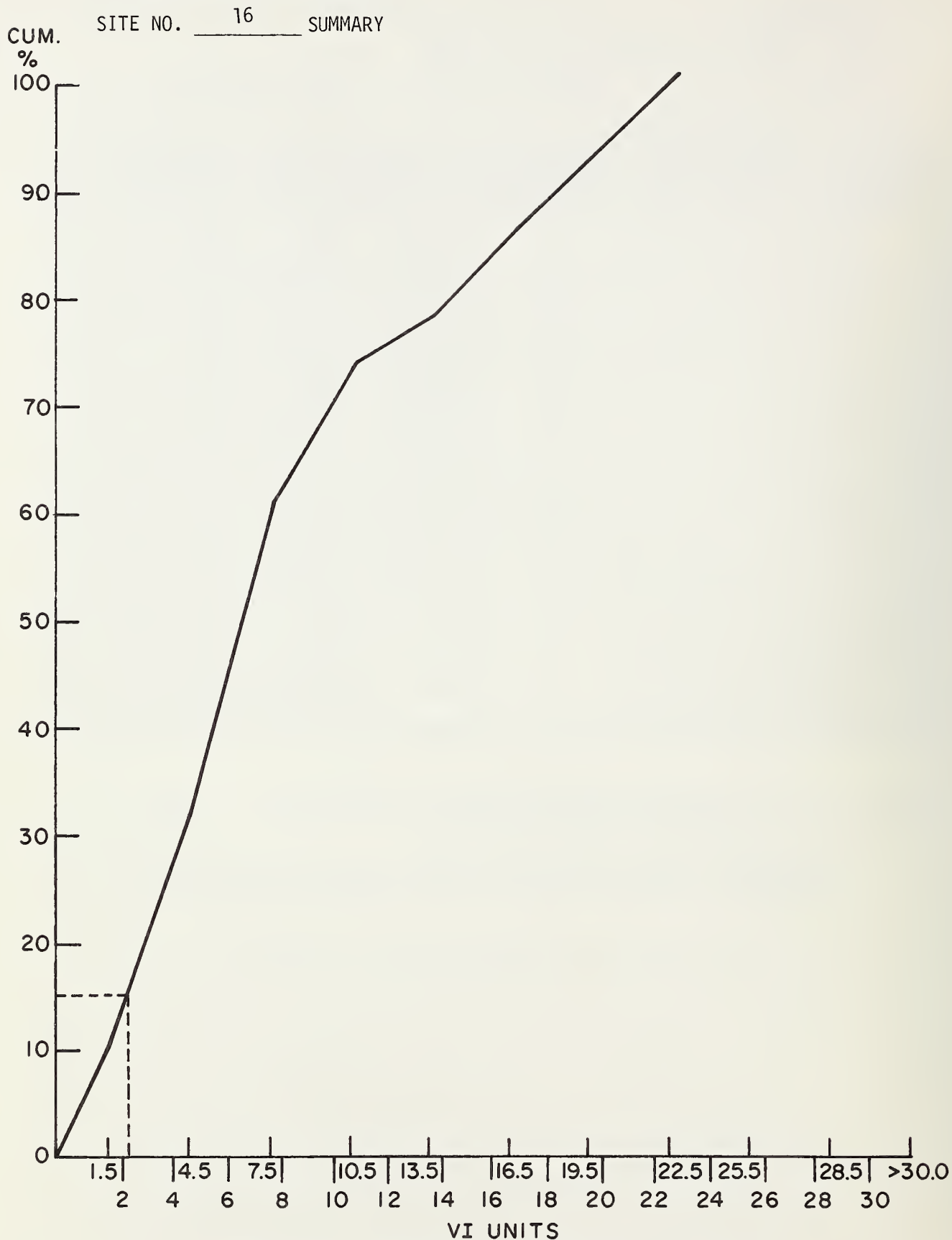
Figure 16. Frequency Distribution Plot Form Used
To Obtain DVI_{15} and DVI_{50}.

28.

dividing them by the total non-ambient DVI sampling time (Figure 15). (4) A plot of the master site DVI frequency distribution was performed on the graph sheet shown in Figure 16 and from this plot the 15 percentile DVI (DVI15) was extracted. This number represented the minimum DVI level occurring over 85% of the time when vehicular headlights and other dynamic occurrences were present when measurements were made. From the same frequency distribution plot, the mean DVI or DVI50 was retrieved.

3.4.4 WDVI Analysis

WDVI consisted of the numerical combination of the dynamic and ambient conditions and was calculated by the following formula:

$$WDVI = VI_{15} \left[1 - \left(\frac{N}{N_t} \right) \right] + DVI_{15} \left[\frac{N}{N_t} \right]$$

where VI_{15} = 15th percentile ambient VI

DVI_{15} = 15th percentile non-ambient DVI

N = Total non-ambient time during measurement periods (seconds)

N_t = Total measurement time or the number of TP's multiplied by 100(seconds.)

In sum, WDVI data is the pooling of an area (VI15) and a time (DVI15) basis of analysis.

3.4.5 Horizontal Illumination

The discrete illumination measurements at each target location per field site underwent only minimal reduction. Mean Illumination HFC50 and the 15th percentile illumination HFC15 were calculated for each field site.

4. ACCIDENT DATA

4.1 DATA COLLECTION

Accident data was gathered for each of the eighty-four sites in our survey. The study periods include the calendar years 1974, 1975, and five months of 1976. Each site was analyzed using seven variables for four accident types under two weather conditions. These seven variables were combined into more complex composite variables in the statistical analyses discussed in Section 5. The following is a summary of the methods used and problems encountered in preparing the accident data for analyses. The steps for this analysis included 1) determining site limits, 2) finding the lighting type conversion dates, 3) fixing the start and length of the study period, 4) collecting the accident reports, 5) normalizing the accident data, 6) transfering the information to a useable form, and 7) analyzing the accidents for each site.

The limits of each site for the purpose of accident analysis was dependent on several factors. Each site was to have a six block length as determined by the postal numbers. Two examples include Chestnut Street from 39th to 45th Streets (3900 to 4499) and 22nd Street from Market to Spring Garden Street (000 to 599). Each six block site was to have a continuous configuration with respect to area type and geometry, surface type, lighting configuration, and parking conditions. These constraints were determined by field observation.

Conversion dates of lighting systems from mercury to high pressure sodium type lighting was determined by contacting the street lighting department of the city of Philadelphia. This was necessitated by the extensive conversion program in Philadelphia from Mercury to HPS for all arterial and residential streets. Conversion began in 1973 and continued through 1976.

The accident analysis for each site was designed to extend for a one year period.* The calendar year 1974 was chosen for those sites in Philadelphia whose conversion date occurred before January 1, 1974, and for those sites which had not been converted to HPS. Those sites whose conversion date occurred during the year 1974 were studied in the calendar year 1975. The start of the study periods for the remaining sites was contingent on their conversion dates. Generally, the study period began immediately after the lighting system conversion and lasted for one year or until June 1, 1976, the last date for which accident data

_____

* One site had only a 6 month accident history period.

30.

was available. Therefore, a site which was converted in May, 1975 will have seven months of 1975 accident data and five months of 1976 data.

The three sites located in Cheltenham township and the four sites in the city of Chester were mercury sites. The calendar year 1975 was chosen as the study period for these sites.

Accident data was collected for each site using accidents occurring at night within the site limits. Accidents occurring at intersections were excluded as were accidents listed as dawn or dusk. The intersection accidents were excluded because visibility at the intersection of two streets is normally much different than the visibility at mid block sections. Dawn and dusk accidents were excluded because the roadway lighting condition could be much different than nighttime, depending on the ambient sunlight and the number of roadway luminaires actually energised (photo controls vary in sensitivity). Also, bus or train accidents were excluded, so as to not falsely inflate injury figures. All data for Philadelphia was available from the office of the traffic safety engineer. Data for the three Cheltenham sites was summarized and mailed to us by the Cheltenham Police Department. Accident reports for the four sites in Chester were available from the Chester Police Department.

4.2 DATA ANALYSIS

In order to analyze the accident data more accurately, it was desirable to have all sites on a comparable year basis. Since the majority of sites used 1975 data, the statistics of sites using other than 1975 data were to be multiplied by the ratio of the total 1975 accidents to the total accidents of the year chosen for analysis. The total accidents for 1974 were 62,345. The total accidents for 1975 were 62,754. The resulting ratio was 1.0065 making a normalization of data unnecessary. Similarly the ratio of the first five months of 1975 to 1976 was 1.059.

Accident information was transferred from official Traffic Accident Reports to FIRL Report Forms, Figure 17. All blanks were filled in and where necessary a short summary was provided. Each site was analyzed with respect to 8 categories. Initially accidents were broken down into dry and wet accidents. Each of these was further broken down into single vehicle-no pedestrian contact, single vehicle-pedestrian contact, multiple vehicle-no pedestrian contact, and multi-vehicle pedestrian contact. These eight categories can be combined to produce composite figures for each site and a composite severity index. (See Section 5).

4.3 DISCUSSION OF RESULTS

The conversion dates of sites from Mercury vapor to High Pressure Sodium was neither fully indexed nor up to date in the Philadelphia Street Lighting Department's files. The time lag between actual conversion work being completed and entry into the filing system was as much as eighteen months for some sites. This necessitated researching Phila-

31.

SITE_____FROM_____TO_____

PERIOD OF STUDY   1973   1974   1975   1976   _____

ACCIDENT CASE NO._____

DATE_____

ACCIDENT TYPE: *SINGLE VEHICLE - NO PED*   *SINGLE VEHICLE - PED CONTACT*

                 MULT. VEHICLE - NO PED   *MULT. VEHICLE - PED CONTACT*

TIME OF ACCIDENT: DAY_____

                  NIGHT_____

WEATHER: DRY_____

         WET_____

NO. VEHICLES INVOLVED_____

NO. PED INJURIES_____

      FATALITIES_____ AMBULANCE?

NO. VEH. OCC. INJURIES_____

          FATALITIES_____ AMBULANCE?

EST. TOTAL PROPERTY DAMAGE ($) _____

                              _____

NOTES:

Figure 17. Accident Report Form

32.

Philadelphia Electric Company bills to the city and noting completion
dates for our sites.

During the initial site conversion survey, it was noted that the
conversion dates of a few sites would not allow sufficient accident data.
Alternatives were then chosen for these sites.

Accident Reports for the years 1975 and 1976 had not been classified
by the Philadelphia Office of Traffic Safety into intersecting and non-
intersecting accidents nor were they arranged alphabetically as is the
normal procedure. This necessitated referencing all accidents for those
years to find pertinent data.

Accident Data was ultimately obtained for all 84 sites. This in-
cluded twenty-nine sites using 1974 as a study period, thirty-nine sites
using 1975 as a study period, and one site using 1976 data. Fifteen
sites used a split-study period between 1975 and 1976. A total of 322
accidents were analyzed.

5. DATA ANALYSIS

The main objective of this part of the research was to develop statistical relationships between the visibility variables and the accident frequency and cost variables. In meeting this objective we have developed regression equations, analyzed the effectiveness of the visibility variables separately and in combinations and have developed average accident costs. The statistical analyses are all presented in in Appendix C; this section provides a summary and interpretation of the statistical results and a summary of accident costs. Together they provide a relationship between visibility and accident costs.

5.1 VARIABLES

The variables included Visibility, Demographic and Socio-economic, and Accident histories.

5.1.1 Visibility Variables

The following visibility variables were originally selected for possible input into the statistical analyses.

1. Mean Horizontal Illumination (HFC50)
2. 15th Percentile Horizontal Illumination (HFC15)
3. Mean Pavement Luminance (LTRAP)
4. Mean VI (VI50)
5. 15th Percentile VI (VI15)
6. Mean DVI (DVI50)
7. 15th Percentile DVI (DVI15)
8. Weighted Dynamic Visibility Index (WDVI)

Each of the above 8 variables were described in Section 3 of this report.

5.1.2 Demographic and Socioeconomic Variables

Site demographic and socioeconomic variables were of two types and were gathered from three sources: (1) Area designations were based on categorization of sites as described in Section 2 (i.e., CBD, OBD, RF). (2) Population densities were obtained from census tract information provided by the National Planning Data Corporation, and (3) census characteristics were obtained from Tables P-1 through P-4 of the Philadelphia, Pa. - New Jersey SMSA 1970 Census of Population and Housing (4). Population densities and census characteristics were gathered for all of the 134 census tracts in which the 84 sites were located. Values of the

34.

site demographic variables were obtained after weighting the number of tract sub-areas for all tracts surrounding or adjoining each site.

Area Designation. According to the principal uses of the neighborhood in which each site lay, the sites were classified as either Central Business District (CBD), Outlying Business District (OBD), or Residential Fringe (RF). In order to derive quantitative variables that could be used in the statistical analyses, three dummy variables were created. These dummy variables (with numeric values in parentheses) were:

CBD (1) vs. Other (0)
OBD (1) vs. Other (0)
RF (1) vs. Other (0)

Density. Site population densities were calculated as the number of persons per square mile of residential/institutional non-water land area.

Census Characteristics. For each census tract, the following data were gathered from the SMSA books:

Table P-1

(a) All Persons
(b) White
(c) Male under 5 years
(d) Male 5-9 years
(e) Male 10-14 years
(f) Male 55-59 years
(g) Male 60-64 years
(h) Male 65-74 years
(i) Male 75 years and over
(j) Female under 5 years
(k) Female 5-9 years
(l) Female 10-14 years
(m) Female 55-59 years
(n) Female 60-64 years
(o) Female 65-74 years
(p) Female 75 years and over
(q) Persons per household

Table P-2

(r) Native of native parentage
(s) Persons of Spanish language
(t) Percent high school graduates

Table P-3

(u) Total employed, 16 years old and over
(v) Professional, technical, and kindred workers

(w) Managers and administrators, except farm
(x) Sales workers
(y) Clerical and kindred workers

Table P-4

(z) Median income (All families)

From these census tract characteristics, the following eight variables were created for each site.

Percentage Non-Spanish Speaking White [(b-s/a)]
Percentage Native of Native Parentage [r/a]
Median Income   [z]
Percentage High School Graduates   [t]
Percentage White Collar Workers   [(v+w+x+y)/u]
Persons per Household   [q]
Percentage Young   [(c+d+e+j+k+l)/a]
Percentage Old   [(f+g+h+i+m+n+o+p)/a]

These census variables were chosen to represent the clusters of "assimilation", "socioeconomic", and "family" that were derived by Tryon (5) and shown by Kay (6) to be related to community deterioration in the Philadelphia area. While some latitude existed in terms of the specific census variables to represent the clusters, one consideration followed in the choice of some of the variables was their potential relationship with pedestrian-related accidents.

5.1.3 Accident History Variables

Nighttime accident data were gathered for each of the following eight conditions:

Dry Weather - Single Vehicle - No Pedestrian Contact
Dry Weather - Single Vehicle - Pedestrian Contact
Dry Weather - Multiple Vehicles - No Pedestrian Contact
Dry Weather - Multiple Vehicles - Pedestrian Contact
Wet Weather - Single Vehicle - No Pedestrian Contact
Wet Weather - Single Vehicle - Pedestrian Contact
Wet Weather - Multiple Vehicles - No Pedestrian Contact
Wet Weather - Multiple Vehicles - Pedestrian Contact

In addition, data were pooled to form composite accident conditions date:

Dry Weather - Single Vehicle
Dry Weather - Multiple Vehicles
Dry Weather - Total Vehicles
Wet Weather - Single Vehicle
Wet Weather - Multiple Vehicles
Wet Weather - Total Vehicles

Wet weather accident data were gathered for the purposes of comparative analyses. For each of the above conditions, the following 13 variables were calculated for each site:

      a.   Number of accidents
      b.   Number of vehicles involved
      c.   Number of pedestrian injuries
      d.   Number of vehicle occupant injuries
      e.   Number of pedestrian fatalities
      f.   Number of vehicle occupant fatalities
      g.   Number of property damage accidents
      h.   Number of total injuries (c+d)
      i.   Number of total fatalities (e+f)
      j.   Number of pedestrian injuries plus fatalities (c+e)
      k.   Number of vehicle occupant injuries plus fatalities (d+f)
      l.   Number of total injuries plus fatalities (c+d+e+f)
      m.   Composite severity

Composite severity for each site was determined by considering the ratios:

      a.   cost per fatality to cost per property damage accident and
      b.   cost per injury to cost per property damage accident, as published by National Safety Council. An equation was developed as follows:

$$CS = X + 7.54Y + 183Z \qquad = \text{Composite Severity, where}$$
$$X = \text{Number of Property Damage Accidents}$$
$$Y = \text{Number of Injuries}$$
$$Z = \text{Number of Fatalities}$$

Using Average Daily Traffic (ADT) volumes, provided by Philadelphia Department of Streets, all accident statistics were transformed into rates per 10,000 vehicles ADT volume. Using night Volumes (17% of day volume), a similar transformation was made.

The value of 17% of the ADT chosen for night traffic volume estimates is derived from several sources. The distribution of the percent of ADT for each hour during a 24 hour period for urban traffic from several sources* were compared and found to be in agreement. The true nighttime period was approximated as the nine hour period from End of Evening Nautical Twilight (EENT) to Beginning of Morning Nautical Twilight (BMNT), or end of dusk to beginning of dawn, occurring between the

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* Sources compared included automatic traffic recorder count summaries (adjusted to represent AADT) for the Philadelphia area and a summary of hourly ADT variation for urban traffic, shown in Figure 3.6 of the *Highway Capacity Manual; HRB Special Report 87*, 1965.

hours of 8:00 P.M. and 5:00 A.M. Each increment of the percent of ADT during this period was summed for a total of 17%.*

Frequency distributions were produced for each accident history variable under each condition. On the basis of these frequency distributions, it was determined that the only accident history variables and conditions for which there was sufficient variability to proceed with the analyses were:

(a) Number of Accidents
(b) Number of Vehicles Involved
(c) Number of Property Damage Accidents
(d) Composite Severity

all measured for the condition Dry Weather – Total Vehicle Accidents. The remaining Dry Weather variables were not analyzed because there were 56 sites with no injuries or fatalities (i.e., no data in 56 of 81 cells).

All "accidents" are actually "number of night accidents per 10,000 nighttime vehicles", (the criteria) were corrected for ADT therefore all analyses were done with traffic volume controlled. This does not account for the effect of traffic volume, but rather corrects for it. There were a total of 322 accidents analyzed or about 4 per site.

5.2 SUMMARY OF REGRESSION ANALYSES

The following summarizes the statistical analyses performed in this part of the research, including a description of each step and the results obtained in each step. (For a complete discussion of the analysis the reader is directed to Appendix C):

1. For Dry Weather Accidents, determine, on the basis of the number of sites for which one or more accidents occurred, those vehicle-pedestrian accident conditions and composite accident conditions to be studied.

    Dry Total (Pedestrians and No Pedestrians, single and multiple vehicles), with 71 sites having one or more accidents, was determined as the only condition to be studied.

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* In the statistical analysis that were performed, it is immaterial whether 17% or any other value is used. If any other percentage is used as a nighttime ADT figure, the regression equation derived in § 5.2 can be modified by multiplying the predicted accident rate by the ratio of the new nighttime % to 17% (e.g, $\left(\frac{25}{17}\right)$ x Accident rate for a 25% night volume).

2. Determine the Accident History variables with the best distribution properties to serve as criteria in the regression analyses.

Number of Accidents, Number of Vehicles Involved, Number of Property Damage Accidents, and composite severity were chosen. Insofar as there were only 28 sites with one or more injuries or fatalities (and 56 sites with no injuries or fatalities), none of the accident history variables involving injuries or fatalities could be studied further.

3. Prior to the regression analyses, eliminate redundant predictors with lower (in comparison to that variable with which it is redundant) predictor-criterion correlations.

HFC50 (redundant with HFC15) and WDVI (redundant with VI15) were eliminated in the set of visibility variables. OBD vs. other was eliminated in the set of area designation variables (all of the information from a categorized variable taking on three values is contained in two dummy variables created from that categorical variable).

THE FOLLOWING RESULTS ARE GIVEN ONLY FOR NUMBER OF ACCIDENTS AS THE CRITERION

4. The criterion was regressed on 17 predictors (2 area designation, density, 8 demographic-socioeconomic, 6 visibility) in order to determine the multiple R for the 17 predictors, and the contribution of the three 15th percential visibility variables and LTRAP over and above the demographic-socioeconomic variables.

A multiple R of .57 (p<.05) was obtained. The 15th percentile visibility variables and LTRAP did not improve upon the demographic-socioeconomic predictors.

4*. The criterion was regressed on the three 15th percentile variables and LTRAP to determine the multiple R for these variables.

A multiple R of .34 (p<.05) was obtained. From step 4 and 4, it was found that while these visibility variables can be used to predict the criterion, they do not add to the predictability using demographic-socioeconomic variables.*

5. Demographic-socioeconomic predictors with predictor-criterion correlations not statistically significant at the .20 level, one tailed (an "r" of $\leq$ .0948) were eliminated as were 50th percentile values of the remaining visibility variables, and the regression analysis was re-run.

Using 10 predictors (6 demographic-socioeconomic plus 4 visibility), a multiple R of .48 (p<.05) was obtained.

6. Eliminating all predictors that entered the solution in step 5 with an F value of <1.0 (testing the contribution of that predictor upon entering the solution), the regression analysis was re-run.

   Using 5 predictors (3 demographic-socioeconomic plus 2 visibility), a multiple R of .47 (p<.01) was obtained.

7. Eliminating all predictors which, according to an F test, if individually dropped from the solution of step 6, would not lead to a statistically significant loss in predictability, the regression analysis was re-run.

   Using CBD vs. Other, Density, HFC15, and VI15, a multiple R of .47 (p<.001) was obtained. The equation:

   No. of Accidents = 1.52+2.67 (CBD vs. Other) +.0000855 (Density) +1.26 (HFC15) - .415 (VI15) reveals that larger numbers of accidents occur in CBD areas of high density with low VI15, and high HFC15.

8. (FOR NUMBER OF ACCIDENTS ONLY)

   Recognizing the counter-intuitive relationship of HFC15 (intuitively, larger numbers of accidents should occur for low HFC15, this predictor was eliminated and the regression analysis was re-run.

   A multiple R of .40 (p<.01) was obtained for the equation:

   No. of Accidents = 2.02+3.07 (CBD vs. Other) +.0000897 (Density) - .258 (VI15). While more intuitively acceptable, this equation is significantly poorer at the .05 level than the 4-predictor of step 7.

9. Using the same predictors as in step 6, regression analyses were performed for the conditions Dry Single Vehicle and Dry Multiple Vehicle [to determine that analyses of the composite condition (Dry Total) did not distort analyses of its component conditions] and Wet Total [to test whether the visibility variables (measured in dry weather) will predict wet weather accidents.]

   The demographic-socioeconomic predictors were relatively more important for predicting Dry Single Vehicle accidents, and the visibility variables were relatively more important for predicting Dry Multiple Vehicle accidents, in comparison to Dry Total accidents. Wet Total accidents were related to demographic and socio-economic variables only.

40.

10. Determine whether 15th percential visibility variables are better than 50th percentile visibility variables by replacing 15th percentile visibility variables in equations of step 7 with corresponding 50th percential visibility variables. Also, comparing VI15 and DVI15 to DVI50 in combination with CBD vs. Other and Density in predicting the criterion.

   15th percential visibility variables produce higher multiple R's than 50th percentile visibility variables.

11. With CBD vs. Other and Density also in this equation compare HFC15, VI15, and DVI15 in terms of multiple R.

   VI15 is best, followed by DVI15, with HFC15 poorest.

12. Test the effect of Site Length on Visibility, Demographic - Socio-economic and accident variables. Determine new multiple R's and new regression equations.

   The correlation of site length with the Visibility, Demographic - Socioeconomic and accident variables was low. The new multiple R's were .50 (vs. .47 without site length - Step 7 above) and .43 (vs. .40 without site length - Step 8 above). The new 4 predictor equation is:

   244+6.91)(CBD vs. Other) + .000154 (Density) +2.93 (HFC15) - .899 (VI15).

   The new 3 predictor equation is 3.61+7.85 (CBD vs. Other) +.000164 (Density) - .532 (VI15).

5.3 INTERPRETATION OF RESULTS

The general findings can be interpreted as follows:

- The most important independent variables in predicting total accident histories for the study sites are:

      VI15
      HFC15
      Population Density (POP)
      CBD vs. Other area types (CBD)

- POP and CBD have positive correlations with Accident history which imply that more accidents occur in CBD areas than in other types and more accidents occur in high population density areas than in low density areas. This result is significant for both total accident frequency and for accident frequency normalized by traffic volume.

- VI15 has a negative correlation with accident history
  indicating a safer environment under high visibility
  conditions than under low visibility conditions. This
  is true for unadjusted and adjusted (by volume) accident
  histories.

- HFC15, which incorporates both illumination level and
  uniformity into one measure, does not negatively correlate
  with accident history (opposite to VI15) and in fact for
  the 84 sites chosen it was apparent that the exact opposite
  relationship was true (i.e., higher HFC15 results in higher
  accident rates.)

The interpretation of this result is probably that illumination and
uniformity are not the basis for safer lighting design. This is an
agreement with the results of Gallagher (2) who found inconsistent (and
insignificant) relationship between illumination (and uniformity) and
driver performance.

- No correlation was found between any of the pairs of the
  preceding 4 variables indicating that the above results
  are not redundant (e.g., it is not necessarily true that
  the effects of CBD and high population density or CBD and
  low VI15 are equivalent).

The regression equation incorporating all four of the above variables
(including site length) is: 2.44+6.91 (CBD vs Other) +.000154 (density)
+2.93 (HFC15) - .899 (VI15).

- If HFC15 is removed from the regression analyses because
  of its improper prediction (i.e., wrong direction) the
  validity of the resulting equation is weaker, as discussed
  in Appendix C, but still significant. The equation is
  3.61+7.85 (CBD vs Other) +.000164 (density) - .532 (VI15)

- If only VI15 is used in a regression equation (i.e., drop
  the socio-economic and demographic variables) then all
  statistical validity is lost. This implies that for the
  sites selected for analyses, *visibility* alone (as defined
  by VI15) is not a significant predictor of accident history.
  If the visibility variables (VI15 and HFC15) are dropped from
  the regression equation a significant loss in predictability
  results.

- The regression equations derived for dry weather conditions
  will not predict wet weather accidents. In fact is was
  impossible to derive a regression equation incorporating
  any dry weather visibility data that would accurately predict
  wet weather accidents. This can be interpreted as a signi-
  ficent finding in that wet weather visibility is much

different than dry weather visibility and any differences
in wet, nighttime accident histories should not be related
to our visibility measurements, which were made totally
during dry weather conditions.

● Of the original visibility variables:

   HFC50 – Mean Horizontal Illumination
   HFC15 – 15th Percentile Horizontal Illumination
   VI50 – Mean Visibility Index
   VI15 – 15th Percentile
   DVI50 – Mean Dynamic Visibility Index
   DVI15 – 15th Percentile Dynamic Visibility Index
   LTRAP – Mean Pavement Luminance (C.I.E. method)
   WDVI – Weighted Dynamic Visibility Index

The best single variable is VI15, followed by HFC15 (reverse effect),
DVI15 and LTRAP. The remaining 4 are correlated with one ot the preceed-
ing (and of less value).

In comparison, all 15th percentile variables are better predictors
of accident history than 50th percentile variables and VI variables are
better as predictors than DVI variables, HFC variables or pavement lumi-
nance variables (LTRAP).

Because of insufficient quantities of injury and fatality data for
the 84 sites, it was impossible to develop statistically valid relation-
ships between the predictor variables and more specific types of acci-
dents (e.g., injury vs fatality vs property damage or pedestrian vs
non-pedestrian etc.) Additional years of accident data would be required
for these analyses.

5.4 DISCUSSION

A number of important points are raised as a result of these analy-
ses. First, accident rate is inversely proportional to visibility level
(VI15); increasing the visibility results in a decrease in accident rate.*
However accident rate was found to be directly proportional to illumina-
tion level; increasing the mean (or 15th Percentile) illumination level
also increases accident rate.* No correlation however was found between
VI15 and HFC15 hence neither of the above lighting variables can predict
the other with any accuracy.

As HFC15 is increased, glare (L_v) is increased which may be causing
the reduction in VI15 and hence the increase in accident rate. However,
this variable (L_v) was not used as a separate predictor in our analysis,
hence no statistical results are available.

_____

* With area type and population density fixed.

43.

As a result of our VI computer program runs, two additional observations were noted (although not statistically validated).

1. As pole spacing is increased from 100 ft. (30m) to 250 ft. (76m), while keeping mounting height fixed, both the visibility and the illumination levels decrease.

2. As mounting height is increased from 20 ft. (6m) to 45 ft. (13.7m) the visibility variables *increase* (most noticeably VI15) while the illumination variable HFC50 *decreases* and HFC15 remains relatively constant.

These observations again imply little or no relationship between visibility and illumination alone.

5.5 ACCIDENT COSTS

Data reflecting modern costs of traffic accidents was required for input to the economic analysis so that the regression equation could predict accident costs directly. To obtain modern costs of traffic accidents a literature review was conducted to identify sources of nationwide accident cost data. Such data was available from only two sources: the National Safety Council (NSC) and the National Highway Traffic Safety Administration (NHTSA). The data is presented in Table 1. No data was available to disclose any difference between the costs of daytime and nighttime accidents.

NSC Cost data includes (7)

Wage loss
Medical expenses
Insurance administrative costs
Property damage

NHTSA cost data includes (8)

Production losses – market, home, family, community, funeral, coroners examination report
Legal and court fees
Accident investigation
Loss to other than injured party
Vehicle damage
Traffic delay.

NSC includes only direct costs while NHTSA includes both direct and indirect costs. It was felt that the NHTSA data was more representative and will be used in all further calculations.*

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* There is still disagreement as to which cost is "better". Some decision had to be made and the authors felt that the NHTSA figures and assumptions were somewhat better for our purposes.

Table 1. Accident Costs

Type of Accident	NSC	NHTSA
Fatality	110,000	287,000
Non-Fatal injury (per person)	4,200	3,185
Property Damage Only (per accident)	570	837
Average Cost per accident	1,285	2,130

The regression equation derived earlier in combination with the accident cost data now provides a relationship between visibility (and population density and area type) and accident costs per 10,000 vehicle miles which will serve as the first input into the economic analyses of Section 7. The second input - lighting system costs - is discussed in the next section.

6. LIGHTING COSTS

The objective of this task was to develop modern lighting system costs (1975-1976) which would serve as the second input into the economic analysis for urban and suburban arterial lighting systems. To meet this objective, data was obtained from a small number of utilities and municipalities from direct contacts by FIRL personnel. The data sought included:

- Frequency distributions of modern arterial lighting system components in order to obtain their frequency of usage in the United States.

- Average costs for individual items (e.g., luminaires, poles, wiring, maintenance, energy etc.)

- Total System costs for new and upgraded lighting systems.

Before any new lighting cost data was collected a literature review was made of existing lighting cost data. Two sources of nationwide data were disclosed. The first, NCRHP Report #20 (9) was developed during 1965 and is presently 12 years old. The sources considered (Mercury, Fluorescent and Incandescent) are now in large part becoming obsolete and the tremendous increase in costs since this study have made the data almost worthless for any modern analyses.

The second study, performed in 1972, was an update of the NCHRP data (10). In this study, a cost update was accomplished by considering modern prices for a number of the cost components and modern labor costs and trends. No new light sources (e.g., HPS or LPS) were included. This study suffers also in that modern sources were not included and a second cost update would result in a decrease in the validity of the projected cost data.

A few other individual cost studies were identified, (11-15) but they largely reflect the costs of individual projects, or alternatives for individual projects. They are not useable for any nationwide analyses.

Data is also available directly from manufacturers. However, the cost differences between "retail" or "list" prices and those actually paid by utilities or municipalities are so great as to make this type of data worthless.(9)

In conclusion, a nationwide sample is required to identify average costs and trends for both individual items and total systems. No modern,

nationwide data exists in the literature which could provide a basis for any type of nationwide lighting costs analysis.

6.1 DETERMINATION OF COMMON ARTERIAL LIGHTING SYSTEM COMPONENTS

6.1.1 Introduction

Counts were taken of three basic categories, luminaire types, pole types, and mounting heights, to determine their usage in modern arterial lighting systems. This is illustrated in Tables 2, 3 and 4. The most common types were then chosen for the analysis of total lighting system costs.

6.1.2 Luminaire Lamp Counts

The mercury lamp was found to be used most often, comprising 78% of all luminaire types. High pressure sodium, being the next highest with 11%, and incandescent with 10%. The remaining 1% consisted of low pressure sodium, fluorescent and metal halide types.

Within the two most common luminaire types the predominant wattages were found to be:

- Mercury: 175 - 50% of all Mercury's
  400 - 35% of all Mercury's

- High Pressure Sodium: 150,150R 48% (44%/4%) of all HPS
  400,360R 43% (26%/17%) of all HPS

The incandescent lamps covered such a wide spectrum of lumen outputs/wattages that no one type was found to be predominant.

Table 2. Distribution of Luminaire Types

Type of Luminaire	Number	Percent
Mercury	911,948	78.2
High Pressure Sodium	126,767	10.9
Incandescent	114,904	9.9
Fluorescent	11,873	1.0
Low Pressure Sodium	392	0
Metal Halide	423	0
Total	1,116,307	100

Table 3. Distribution of Pole Types

Type of Pole	Number	Percent
Wood	481,358	55.9
Steel	277,043	32.2
Aluminum	51,857	6.0
Concrete	47,180	5.5
Fiberglass	4,000	.5
Total	861,438	100

Table 4. Distribution of Mounting Heights

Height(ft) *	Number	Percent
15-25 (low)	52,679	5.3
25-35 (medium)	928,934	93.8
36-65 (high)	6,050	.6
Other (under 15 or over 65)	2,445	.3
Total	990,108	100

* 1ft. = 0.3m

6.1.3 Pole Counts

Pole types were broken into three categories, wood, metal and other. The wood pole comprised 56% of all pole types, while the metal, with two sub-categories, steel and aluminum, were 32% and 6%, respectively, of all pole types. The remaining 6% includes concrete and fiberglass.

6.1.4 Mounting Height Counts

Mounting heights were also broken down into three classes: low, medium, and high. Low consists of all heights less than 25' (7.6m) medium being all those heights between 25' (7.6m) and 35' (10.7m) and the high are all those heights above 35' (10.7m). The breakdown, percentage-wise, was totally dominated by the medium height with 94%, the low height comprised 5%, and the high height being 1% of the total. The predominance of medium heights is reflected in the accuracy of the costs for low and high heights. Since the low and high are so rarely

used the figures are accordingly less reliable. This shall be discussed
in more detail in the subsection on pole costs.

6.2 INDIVIDUAL ITEMS: AVERAGE COSTS AND RANGES

6.2.1 Introduction

A system cost can be developed after evaluating the costs of its
individual components. Utilizing the common components from Section 6.1,
individual component average costs were than tabulated as input for the
table of lighting system costs.

6.2.2 Luminaire Costs - Luminaire, Lamp, Ballast, and Wire to Tap
Connection

The costs include luminaire with lamp, wiring to tap connection -
furnished and installed (labor and material). Only for the three most
common luminaire types could average costs be computed with confidence.
The incandescent luminaire had an average cost of $84.00 with a range
of +25% on the low and high values. (Note, that systems with incan-
descent luminaires will not be considered in the lighting system costs
table; only Mercury and High Pressure Sodium.) The Mercury Lamp ave-
raged $126.00 with a fluctuation of -49% for the low and +113% for the
high. The most expensive of the three luminaires was the High Pressure
Sodium averaging $188.00 with a range of approximately +48%. The costs
are summarized below.

- Incandescent $ 84.
- Mercury $126.
- High Pressure Sodium $188

6.2.3 Pole Costs - Pole, Foundation, Transformer Base and Bracket

Table 5 presents average furnish and install costs and ranges for
poles at the three height classes and the components associated with the
pole other than the luminaire, whose costs have already been discussed.
For the pole costs the medium height is the most reliable, since the
medium height is so predominantly used. Even so, the high and low pole
costs appear to be consistent in comparison.

The total pole cost is calculated from several pole components.
The wood pole total cost includes the pole and foundation (at the proper
height) and the bracket, whereas the metal pole includes, the pole and
foundation, and the transformer base. From Table 5, these total costs
are readily extrapolated. For example, a wood pole at the low mounting
height would cost, $109 (wood/low) + $165 (foundation/low) +$65 (bracket)
= $339.

Table 6 illustrates this for all six combinations, with the metal/
low and medium costs utilizing the steel figure since it has been shown

Table 5. Average Cost Summary of Pole Components

Item	Average Cost	Low % DIF (Always -)	High % DIF (Always +)
Wood Pole - Low	$109.	1.8	1.8
Wood Pole - Medium	$181.	68.6	148.6
Wood Pole - High	$298.	5.0	10.7
Steel Pole - Low	$200.	46.5	71.5
Steel Pole - Medium	$393.	86.0	154.4
Aluminum Pole - Low	$149.	34.9	47.7
Aluminum Pole - Medium	$474.	40.9	47.3
Aluminum Pole - High	$569.	23.1	23.0
Transformer Base	$102.	51.0	123.4
Foundations - low	$165.	44.2	61.2
Foundations - Medium	$197.	49.7	123.4
Foundations - High	$235.	25.5	31.9
Wood Pole Brackets	$ 65.	76.8	100.2

Table 6. Total Cost of Poles Without Luminaire ($)

		HT	POLE	FOUND	BRACKET	TB	TOTAL
Wood		Low	109	165	65	--	$339
		Med	181	197	65	--	443
		High	298	235	65	--	598
Metal		Low	200	165	--	102	467
		Med	393	197	--	102	692
		High	569	235	--	102	906

to be used about five times as often, and the metal/high using the aluminum figure since the steel/high figures could not be ascertained.

6.2.4 Wiring Costs

Four types of wiring were evaluated but only two were used for the final system cost tables. Costs include labor and materials. The two types of most importance are aerial and underground wiring. The average cost of aerial being $.99/linear ft. ($3.24/linear meter) and the underground wiring being approximately two times as expensive, with an average cost of $1.99/linear ft. ($6.53/linear meter). The range of values for aerial and underground were quite large, with the low at - 75% for both and the high being +203% for aerial and +108% for underground.

The two types of wiring not used in the total system costs were underground conduit rigid and plastic. Both were of approximately equal costs. The rigid at $13.83/linear ft. ($45.37/linear meter), and the plastic $13.19/linear ft. ($43.20/linear meter). The ranges were similarly large for conduit prices, as for aerial and underground.

6.2.5 Maintenance Costs, Replacement and Cleaning of Luminaires

Again only two luminaire types are of interest, the Mercury and High Pressure Sodium. The maintenance costs of luminaires was calculated in dollars per lamp per year and includes both labor and material. For mercury this was $7.02 per lamp per year, while the high pressure sodium was significantly larger at $23.79 per lamp per year. The ranges of the costs were again quite variable with mercury lamp's low of -78% and high of +144% and high pressure sodium's low value, at -50% and high, +103%.

51.

Prices were obtained for other luminaire types but were not used in the system cost table. Incandescent was $6.45 per year per lamp, Fluorescent was $8.40 per year per lamp, and low pressure sodium was $23.09 per year per lamp. In summary the maintenance costs are:

- Mercury $ 7.02/lamp/year
- High Pressure Sodium $23.79/lamp/year
- Incandescent $ 6.45/lamp/year
- Fluorescent $ 8.40/lamp/year
- Low Pressure Sodium $23.09/lamp/year

6.2.6 Energy and Power Costs

Energy and power costs were divided into two categories. The first category was energy charge per kwh, and the second consisted of all other charges.

These latter charges vary by utility and normally consist of one or more of the following items

1. Minimum charges
2. Energy cost adjustments or fuel adjustment cost
3. Fuel collection balance adjustments
4. Charges for special control equipment (i.e., other than all night service)
5. Switching
6. Facilities changes (per unit or per point of service termination)
7. Capacity charges (per watt)
8. Demand charges (per watt)
9. Taxes

Some of these are per watt (e.g., 2,3,7,8) while others are per unit (e.g., 1,4,5,6). In all further calculations we will assume this cost (i.e., "other power") to be per watt. Neither is 100% correct and it could easily be argued that a per unit "other power" cost is as good. A decision had to be made and we felt the per watt choice was slightly better in that more of the utilities we talked to charge in this manner. The total cost for energy was the sum of the two.

The average costs were computed to be:

- Energy   2.48¢/kwh
- Other   6.20¢/kwh
- Total   8.68¢/kwh

6.2.7 Miscellaneous Costs

This last group is a conglomeration of miscellaneous costs that were not utilized in the lighting system table. They are included here

for informative purposes only. Table 7 includes all miscellaneous item averages and low to high ranges.

Table 7. Miscellaneous Costs

Item	Average Cost	Low % DIF (Always -)	HIGH % DIF (Always +)
Replace or Repair			
Underground Wiring	$ 1.91/ft.*	61.3	57.1
Conduit - Direct Burial	$ 8.64/ft.*	93.0	150.0
Overhead Cable	$ .86/ft.*	72.1	45.3
Defective Photo Control	$13.57	63.2	62.1
Group-Defective Photo Control	$ 1.51	57.6	65.6
Replace Defective Time Clock	$46.22	45.9	81.0
Adjust and Reset Time Clock	$14.22	43.7	45.4
Luminaire Repairs (Per Item)			
Ballast	$77.00	80.5	74.0
Photo Control Recpt.	$22.90	78.2	62.7
Socket or Internal Wiring	$22.40	66.5	86.6
Glassware and Holding Ring	$25.54	87.6	76.2
Pole and/or Bracket Wiring	$38.22	77.8	56.0
Line Tap	$30.57	59.1	63.6
Painting Pole	$20.31	68.8	71.8
Remove and Replace Pole	$625.	57.8	64.2

* Multiply by 3.28 for cost per meter

6.3 PROBLEMS IN AVERAGE COSTS FOR INDIVIDUAL ITEMS

During the analysis certain problems were encountered with particular costs described in Section 6.2. A short discussion of this is necessary.

In general, the individual parts for lighting systems were no trouble except for the lesser utilized items, such as steel poles at high heights (as discussed previously), low pressure sodium and metal halide luminaires. Also, bracket costs had to be averaged over several lengths and two types, steel and aluminum, but the figures for brackets are meaningful nonetheless.

The other costs, e.g., maintenance and energy, were quite troublesome, since methods of maintenance and energy billing vary greatly, with no real standard in practice. Although written policy of utilities and municipalities is usually standard the actual maintenance practices tend to vary with the specific situation encountered. Both maintenance and energy were extensively analyzed and although they are perhaps only a rough estimate, they are suitable for a general system cost.

6.4 TRENDS IN AVERAGE COSTS

Some of the major cost item averages were stratified in two ways: utilities vs. municipalities, and regional areas, to establish trends in the average costs. Table 8 lists those items and their breakdowns in respective categories.

Table 8 illustrates several points. The average luminaire and associated luminaire maintenance costs are higher for utilities than municipalities. The reverse is true for poles and wiring. Energy costs are approximately the same but the "other" costs are considerably larger for utilities since some maintenance charges are frequently included in this cost.

By region, the Northeast, which consists of Pennsylvania, New York and New Jersey areas, is considerably higher than Central and West for luminaires and their associated maintenance costs. The West shows a considerable decrease in energy costs, which reflects the use of their inexpensive hydroelectric power, yet the fixed fees related to energy are relatively higher in the West than the Northeast and Central regions. The Central area: Illinois, Wisconsin, Indiana, Michigan and Ohio, are significantly higher for poles and aerial wiring costs.

6.5 TOTAL ARTERIAL LIGHTING SYSTEM COSTS

6.5.1 Introduction

A stretch of roadway one mile (1.6km) in length was chosen as the basic unit for system costs. The variables for the basic input were

Configuration - one sided
                two sided/opposite
                two sided/staggered

Table 8. Cost Averages by Ownership and Regions ($)

Category	(Luminaires)		(Poles)		(Wiring)		(Maintenance)		(Energy/Power)		
	Mercury	HPS	Wood	Steel	Aerial	Under	Mercury	HPS	Energy	Other	Total
Utility	145	229	134	289	.56	1.94	8.94	32.94	2.31	8.03	10.25
Municipality	114	149	258	510	1.91	2.05	5.40	17.50	2.42	4.28	6.74
Northeast	170	195	143	273	.76	2.53	10.50	28.68	2.54	5.78	8.36
Central	122	188	292	496	2.25	1.64	4.51	14.36	2.60	5.67	8.60
West	90	178	137	341	.52	1.40	5.39	27.75	1.93	7.40	10.83

55.

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Spacing - 50' - 250' in 50' increments
           (15.2 - 76.2 meters in 15.2 meter increments)
Mounting Height - Low <25' (7.6m)
                  Medium 25' - 35' (7.6 - 10.7m)
                  High >35' (10.7m)
Lamp type - 175 M - (low, medium hts.)
            400 M - (medium, high hts.)
            150 HPS (low, medium hts.)
            400 HPS (medium, high hts.)
Pole Type - Wood (new)
            - Metal (new)
            - Existing Wood Pole
```

6.5.2 Tables for Lighting System Costs

The Tables 9, 10 and 11 describe the costs for 50' (15.2m) spacing, one sided configurations and each of the 3 pole types, with a conversion factor for all other configurations and spacings.

6.5.3 Development of Cost Tables (9, 10 and 11)

Assumptions

Certain assumptions were made involving the numbers as shown in the system tables. Average life expectancies for the three materials were estimated at

- luminaires and poles - 20 years
- aerial wiring - 25 years
- underground wiring - 35 years

and an annual interest rate of 6% on municipal bonds was assumed. A trace of the calculations for each item shall be shown, beginning from the left column to the right column on Table 9.

Calculation of Initial and Annual Pole Costs

The first piece of information necessary for the calculations is the number of poles required for each spacing and configuration. Table 12 shows the number of required by each system over a one mile (1.6km) piece of roadway.

Utilizing the pole costs as given in Table 6 we generated the initial costs shown in Tables 9, 10 and 11. Multiplying the pole cost times the number of poles for that particular arrangement/spacing yields an initial cost. The annual cost is just the initial value amortized over the lifetime of the pole. Using a simple interest equation:

Table 9. Lighting System Costs ($) New Wood Poles
(1 Mile (1.6km), one sided, using average cost figures)

SPACE*	HT	LUMINAIRE	WOOD POLE= BRACKET+ FOUNDATION+ POLE		LUMINAIRE		WIRING AERIAL		ENERGY/ POWER		MAIN- TENANCE	TOTAL COSTS	
			INIT	ANN	INIT	ANN	INIT	ANN	ENERGY	OTHER	ANNUAL	INIT	ANN
50'	L	M 175	35,595	3915	13,320	1465	5227	523	1867	4664	737	54,142	13,171
50'	M	M 175	46,515	5116	13,320	1465	5227	523	1867	4664	737	65,062	14,372
50'	H	M 175	69,790	6907	13,320	1465	5227	523	1867	4664	737	88.337	16,163
50'	M	M 400	46,515	5116	13,320	1465	5227	523	4265	10,664	737	65,062	22,770
50'	H	M 400	62,790	6907	13,320	1465	5227	523	4265	10,664	737	81,337	24,561
50'	L	HPS 150	35,595	3915	19,740	2171	5227	523	1599	3998	2498	60,562	14,704
50'	M	HPS 150	46,515	5116	19,740	2171	5227	523	1599	3998	2498	71,482	15,905
50'	H	HPS 150	62,790	6907	19,740	2171	5227	523	1599	3998	2498	87,757	17.696
50'	M	HPS 400	46,515	5116	19,740	2171	5227	523	4265	10,664	2498	71,482	25,237
50'	H	HPS 400	62,790	6907	19,740	2171	5227	523	4265	10,664	2498	87,757	27,028

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 9	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

Note: For low or high calculations the following % changes are approximate:
low: -75% on all except energy/power, e/p = -50%
high = +150% on all except energy/power, e/p = +50%

* 1m = 3.28 ft.

57

Table 10. Lighting System Costs ($) - New Metal Poles
(1 Mile - (1.6km), one sided, using average cost figures)

SPACE*	HT	LUMINAIRE	METAL POLE = TRANSFORMER BASE + FOUNDATION + POLE		LUMINAIRE		WIRING UNDERGROUND		ENERGY/POWER		MAINTENANCE	TOTAL COSTS	
			INIT	ANN	INIT	ANN	INIT	ANN	ENERGY	OTHER	ANNUAL	INIT	ANN
50'	L	M -175	49,035	5394	13,320	1,465	10,138	898	1867	4664	737	72,493	15,025
50'	M	M -175	72,660	7993	13,320	1,465	10,138	898	1867	4664	737	96,118	17,624
50'	H	M -175	95,130	10,464	13,320	1,465	10,138	898	1867	4664	737	118,588	20,095
50'	M	M -400	72,660	7993	13,320	1,465	10,138	898	4265	10,664	737	96,118	26,022
50'	H	M -400	95,130	10,464	13,320	1,465	10,138	898	4265	10,664	737	118,588	28,483
50'	L	HPS-150	49,035	5394	19,740	2,171	10,138	898	1599	3998	2498	78,913	16,558
50'	M	HPS-150	72,660	7993	19,740	2,171	10,138	898	1599	3998	2498	102,538	19,157
50'	H	HPS-150	95,130	10,464	19,740	2,171	10,138	898	1599	3998	2498	107,242	21,628
50'	M	HPS-400	72,660	7993	19,740	2,171	10,138	898	4265	10,664	2498	102,538	28,489
50'	H	HPS-400	95,130	10,464	19,740	2,171	10,138	898	4265	10,664	2498	125,008	30,960

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 10	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

NOTE: For low or high calculations the following % changes are approximate:
low: -75% on all except energy/power, e/p = -50%

high = +150% on all except energy/power = +50%
* 1m = 3.28 ft.

58.

Table 11. Lighting System Costs ($) - Existing Wood Poles
(1 Mile - (1.6km), one sided, using average cost figures)

SPACE*	HT	LUMINAIRE	EXISTING WOOD POLE = BRACKET		LUMINAIRE		ENERGY/POWER		MAINTENANCE	TOTAL	
			INIT	ANN	INIT	ANN	ENERGY	OTHER	ANN	INIT	ANN
50'	L	M -175	6825	410	13,320	1465	1867	4664	737	20,145	9143
50'	M	M -175	6825	410	13,320	1465	1867	4664	737	20,145	9143
50'	H	M -175	6825	410	13,320	1465	1867	4664	737	20,145	9143
50'	M	M -400	6825	410	13,320	1465	4265	10,664	737	20,145	17,541
50'	H	M -400	6825	410	13,320	1465	4265	10,664	737	20,145	17,541
50'	L	HPS-150	6825	410	19,740	2171	1599	3998	2498	26,565	10,676
50'	M	HPS-150	6825	410	19,740	2127	1599	3998	2498	26,565	10,676
50'	H	HPS-150	6825	410	19,740	2127	1599	3998	2498	26,565	10,676
50'	M	HPS-400	6825	410	19,740	2127	4265	10,664	2498		20,008
50'	H	HPS-400	6825	410	19,740	2127	4265	10,664	2498	26,565	20,008

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 11	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

NOTE: For low or high calculations the following % changes are approximate:
low: -75% on all except energy/power, e/p= -50%
high =+150% on all except energy/power, e/p = +50%
* lm = 3.28 ft.

Table 12. Number of Poles Per System by Spacing
and Configurations

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50' (15.2m)	105	210	210
100' (30.5m)	52	104	104
150' (45.7m)	35	70	70
200' (61.0m)	26	52	52
250' (76.2m)	21	42	42

$$\text{Annual cost} = \frac{P + P \times N \times I}{N}$$

where P = Principal (initial cost)
N = No. of years
I = interest rate

For example, take a one sided, 50' (15.2m) spacing, wood pole at the low mounting height. The initial cost equals 105x$339 = $35,595. The annual cost equals

$$= \frac{\$35,595 + \$35,595 \times 20 \times .06}{20} = \$3,915$$

The equation was used on all pole types and heights. Note that for Table 11, only the bracket costs have been used since the pole and foundation already exist, at no additional charge.

Calculation of Luminaire Costs, Initial and Annual

The luminaire costs are calculated in exactly the same manner as the poles, i.e., the number of poles multiplied by the cost of the luminaire type. The averages, as given before, were Mercury = $126.00, and High Pressure Sodium = $188.00.

Applying the equations previously discussed for Mercury,

- initial cost = $126 x 105 poles = $13,320
- annual cost = $\frac{\$13,320 + \$13,320 \times 20 \times .06}{20}$ = $1465

The same has been done for High Pressure Sodium.

Calculation of Wiring Costs: Initial and Annual

The wiring costs are similar but hinge only on one feature, one or two sideness. If the case is one sided, only one mile (1.6km) of wire is used, and if two sided, two miles (3.2km).

Assuming a one sided configuration with aerial wiring this yields,

$$5280 \text{ ft. x } .99\text{¢/linear ft.} = \$5,227\text{/mile (per 1.6km)}$$

for the initial cost. The annual is amortized as before but over 25 years, the lifetime of overhead cable. For wood poles, aerial wiring is the input (Table 9), and for metal poles, underground wire is used (Table 10).

Calculation of Energy and Power Costs

Calculation of the number of kwh/yr for each wattage is necessary. The equation is:

lamp kw x average burn time (hrs/yr) = Number of kwh/yr.

For
- M 175:   175kwx4095 hrs/yr = 716.625 kwh/yr
- HPS 150:   150kwx4095 hrs/yr = 614.25 kwh/yr
- HPS and M 400:   400kwx4095 hrs/yr = 1638.0 kwh/yr

To get the annual costs, take the average cost per kwh and multiply it times the kwh/yr. This will give cost/year, or annual cost.

The cost per kwh was established in Section 6.2.6 as*

- o Energy 2.48¢/kwh
- o Other 6.20¢/kwh
- o Total 8.68¢/kwh

Table 13 illustrates the cost per lamp per year for each luminaire type. The value in Table 13 times the number of luminaires for that system (105) is the total cost for a 1 mile (1.6km) roadway.

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* Ballast loss has not been included as a cost factor, it can range from as low as 5% to as high as 15% depending on ballast design. It is easily kept to a maximum of 10% if proper specifications and designs are used. (Personal contact with C. Oerkvitz, Philadelphia Street Lighting Engineer)

Table 13. Power and Energy Annual Cost by Luminaire Size

	Cost/Kwh	150W	175W	400W
Energy	2.48¢	$15.23	$17.78	$ 40.62
Other	6.20¢	$38.08	$44.42	$101.56
Total	8.68¢	$53.31	$62.20	$142.18

Calculation of Maintenance Costs

The calculation of annual maintenance costs utilizes the average costs previously determined for Mercury and High Pressure Sodium luminaires (average cost per lamp per year) times the number of luminaires in the given system.

- M = $ 7.02/1amp/year x 105 lamps = $ 737/year
- HPS = $23.79/1amp/year x 105 lamps = $2498/year

Calculation of Total Costs; Initial and Annual

The total initial cost is the sum of initial pole cost, initial luminaire cost, and initial wiring cost. The total annual cost is just the sum of all annual costs plus the energy/other costs (which are annual costs) and maintenance costs.

Modifications for Other Systems and High and Low Figures

For each of the other systems a factor is given at the bottom of Tables 9-11 for a cost modification. For example, if the system desired was a 150' (45.7m) spacing, two-sided configuration, using low wood poles and M 175, the total initial cost would be

$54,142 x .72 = $38,982

All other costs are multiplied by the factor of .72 to get the appropriate costs.

Also listed in Tables 9-11 are modifications necessary if one uses the high or low values rather than the average costs. The high/low percentage changes are round numbers, averaged over all system components. A more accurate figure could be obtained by utilizing individual component high/low percentages as given in Section 6.2.

6.6 UPGRADING ARTERIAL LIGHTING COSTS

6.6.1 Upgrading Systems

A cost table similar to Tables 9-11 can be generated for any desired upgraded system. Three such systems shall be shown here, all requiring only a luminaire change.

$$M\,400 \longrightarrow HPS400$$
$$M\,400 \longrightarrow HPS150$$
$$M\,175 \longrightarrow HPS150$$

Only three components are necessary for the upgrading costs, the luminaire cost (to replace the old luminaires), the change in energy cost, and the change in the maintenance cost. It is assumed that either the original system is already paid off, in which case the table gives the actual cost, or the old system is still being paid for and therefore the costs to upgrade are in addition to the costs of the existing system. Another assumption is that the entire luminaire is replaced, i.e., lamp, luminaire, and ballast.

Tables 5, 14, 15 and 16 provide the costs for the three chosen upgraded systems. The factors for Tables 9-11 are applicable to Tables 14-16, but have been multiplied through for convenience.

The initial cost is only the cost to install the new luminaire. The annual cost is the sum of the following items.

(1) Luminaire initial cost amortized over 20 years
(2) Change in the cost of Energy = Energy (new) - Energy (old)
(3) Change in the cost of maintenance = Maintenance (new) - Maintenance (old)

All of these costs are taken from Tables 9-11.

6.6.2 Upgrading Systems - Lamp Only

It is possible that an upgrade may require only a change of the lamp, not the luminaire and ballast. This is possible if the installation being considered utilized a premium ballast (reactor type) that is compatible with the HPS retrofit lamp. Tables 14-16 can be modified very simply if the *lamp* cost is known. Unfortunately, only a few roadway lighting systems have been identified where such simple upgrading is possible.

Upgrading Costs (B)

Table 14.   M400 ————→HPS400

Arrangements	Spacing	Initial	Annual	Energy Change	Maintenance Change	Total Annual
1 Sided	50'	19740	2171	0	1761	3932
	100'	10067	1107	0	898	2005
	150'	7106	782	0	634	1416
	200'	5330	586	0	475	1061
	250'	4540	499	0	405	904
2 Sided and Staggered	50'	39480	4342	0	3522	7864
	100'	20135	2214	0	1796	4010
	150'	14213	1563	0	1268	2831
	200'	10660	1172	0	951	2123
	250'	9080	999	0	810	1809

* 1m = 3.28 ft.

Table 15.   M400 ————→ HPS150

Arrangements	Spacing	Initial	Annual	Energy Change	Maintenance Change	Total Annual
1 Sided	50'	19740	2171	-2666	1761	1266
	100'	10067	1107	-1360	898	645
	150'	7106	782	- 960	634	456
	200'	5330	586	- 720	475	341
	250'	4540	499	- 613	405	291
2 Sided and Staggered	50'	39480	4342	-5332	3522	2532
	100'	20135	2214	-2719	1796	1291
	150'	14213	1563	-1920	1268	911
	200'	10660	1172	-1440	951	683
	250'	9080	999	-1226	810	583

* 1m = 3.28 ft.

Table 16. M400 ─────────→HPS150

Arrangements	Spacing	Initial	Annual	Energy Change	Maintenance Change	Total Annual
1 Sided	50'	19740	2171	- 268	1761	3664
	100'	10067	1107	- 137	898	1868
	150'	7106	782	- 97	634	1319
	200'	5330	586	- 72	475	989
	250'	4540	499	- 62	405	842
2 Sided and Staggered	50'	39480	4342	- 536	3522	7328
	100'	20135	2214	- 273	1796	3737
	150'	14213	1563	- 193	1268	2638
	200'	10660	1172	- 145	951	1978
	250'	9080	999	- 123	810	1686

* 1m = 3.28 ft.

Average costs for lamps could not be ascertained*, but the method is as follows. Table 17 shows the cost of the change in energy costs plus the change in maintenance costs for each upgrade.

Table 17. Upgrade Costs Without Luminaire($)

(50' (15.2m) Spacing, 1 - Sided)

M400 ─────────→ HPS360R   M175 ─────────→ HPS150R

1761   1493

Taking the lamp cost times the number of poles for the 50' (15.2m) spacing, one sided arrangement (105), gives us the initial cost. Using the simple interest equation given earlier, calculate the amortized value of the cost over 20 years. This annual lamp cost plus the figure in Table 17 yields the total annual cost for the upgrade for a 50' (15.2m) spacing, one sided arrangement. Apply the appropriate spacing/ arrangement factor on this total annual cost yields the final value.

─────────
* The actual price is normally done on bid and will range from list to a 70% discount. (e.g., for 150 HPS list = $56 while Philadelphia paid only $17.10 on their last purchase - a 69% discount.)

6.6.3 Upgrading Systems – Raise (or Lower) Height of Luminaire on Wood Poles

Based on data obtained from the City of Philadelphia, the average costs for raising or lowering the height of a luminaire and arm on a single wooden pole is $30, including labor and material. To calculate costs per mile the procedures of 6.5 and 6.6 are followed, with the only cost element being the $30 per pole.

7. ECONOMIC ANALYSIS/OPTIMIZATION

In this section an economic analysis and optimization process has been developed for both new and upgraded lighting systems. It is based on the principals of cost-benefit analysis. The costs are those associated with the installation, operation and maintenance of new or upgraded lighting systems as developed in Section 6. The benefits are those economic savings resulting from a potential reduction in traffic accidents, as estimated based on the statistical model of Section 5.

7.1 NEW SYSTEMS

The analysis can be broken into two parts: An economic analyses based on cost-benefit techniques and an optimization analyses based on economic, energy, visibility and design constraints. Figure 18 presents an overview of the methodology.

7.1.1 Variables

Table 18 lists the configurations of variables that were employed in those analyses. All configurations were analyzed using the VI program discussed in Section 1 to determine VI15.

Table 18. Description of Variables

Variable Description	No.of Levels	Range(5)
Luminaire Type	4	175 & 400 Mercury; 150 & 400HPS
Arrangement (1)	3	1-Sided(near); opposite; staggered
Spacing(1)	5	50'-250' in 50' increments
Mounting Height (2,3)	6	20-45' in. 5' increments
Road Surface (4)	1	new asphalt
Road Width/Direction	2	30'/1-direction; 60'/2-direction
Overhang	1	5' for 30' width; 12' for 60' width

Notes: (1) No 50' staggered or opposite
(2) No 20' MH for 400M or 400 HPS
(3) No 45' MH for 175M or 150HPS
(4) King Reflectance data (16)
(5) 1 ft. = 0.3m
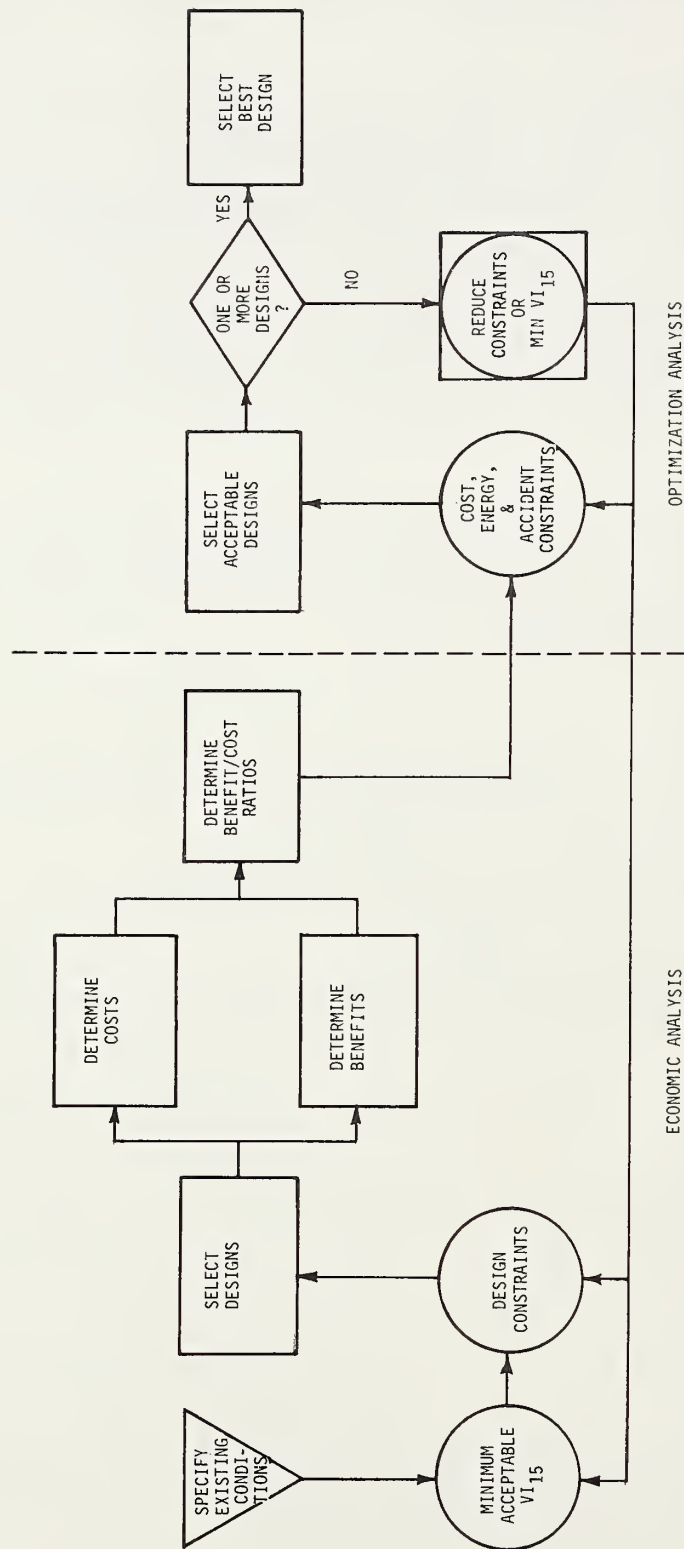
Figure 18. Methodology for New Systems

Of the seven input variables presented in Table 18, a number of restrictions must be noted. Only a limited number of values for each variable were considered. This ranged from one pavement surface to six mounting heights. The geometric variables - arrangement, spacing, mounting height and overhang - were varied over their most common ranges. The luminaire types selected were again four of the most common (exclusive of incandescent which are now too energy inefficient for roadway lighting purposes) and each luminaire was analyzed with only one light distribution per luminaire. The distribution selected were the ones found in Philadelphia and used in an experiment described in Section 3 (except for the 400M unit which matched the specification of the lamp installed on our 7th Street test site)(2). The distributions employed were as follows (1972 IES/ASA):

175M - Medium - semi cutoff - Type II
400M - Medium - semi cutoff - Type IV
150HPS-Medium - non cutoff - Type III
400HPS-Medium - non cutoff - Type IV

Other combination of variables or other light distribution can be analyzed using the VI computer program as long as candlepower distributions for the luminaires under consideration are known.

Only one pavement surface was analyzed. This surface, the type found on our 7th Street test site in Philadelphia, consisted of new asphalt. It was used for validation experiments for the VI computer program as discussed in Section 1. Reflectance data for this surface was obtained from King's data (16) modified by measurements on a sample of surface sent to the Transport and Road Research Laboratory in England.

Pavement surface is probably one of the most important but least understood visibility related variables. From previous computer runs with the VI program we know that a 30% error in visibility can result from an improper pavement reflectance table (e.g., old asphalt instead of new asphalt, according to King's data). However little is actually known in this area of research.

All of the economic analyses conducted in this project are based on one surface only, and any other pavement types must first be analyzed to obtain reflectance data before our methodology can be applied (following the methods set forth in the Design Guide).

7.1.2 Economic Analysis

Using the VI computer program described in Section 1, the elements of Table 21 of Appendix A of the Design Guide* were generated for each combination of variables described in Table 18. A sample is illustrated

_____

* The complete set of tables used for designing new lighting systems based on the FIRL data base is presented in Appendix A of the Design Guide.

Table 19 VI$_{15}$ vs. System Descriptions

VI$_{15}$	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
13.4	60	400M	STG	100	35	11	60/400M/STG/100/35/11/-	23
13.8	60	400M	STG	100	40	11	60/400M/STG/100/40/11/-	24
13.8	60	400M	STG	100	45	11	60/400M/STG/100/45/11/-	25

(1) Configuration: There are 3 codes

    (a) SS = Single side near
    (b) OPP - Both opposite
    (c) STG = Both staggered

(2) Mounting Height: The height of the lamp/luminaire measured from the pavement.
(3) Overhang: The distance from the center of the lamp/luminaire to the curb.
(4) System Code: A code which defines the System in a compact form. It will be used on all sub-
    sequent tables. The form follows the tables order, i.e.,

ROAD   LAMP   CONFIGURATION   SPACING   MOUNTING   OVERHANG   POLE
WIDTH   LUMINAIRE   HEIGHT   TYPE

    Notice that pole type does not exist on Table 19, since it is not a VI15 related item, but it
will appear on all tables involving costs.

(5) Case No.: A unique code number assigned by the computer runs, used for each in transference from
    one table to another.
* i.e., Overhang is equal to the arm length plus 1/2 of the length of the luminaire minus the pole
    setback.

Table 20 Costs of New Systems

SYSTEM CODE	CASE NO.	VI_{15}	ENERGY USE (kwh/mi/yr) (10^2)	INITIAL COST		ANNUAL COST		
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	ENERGY ($/mi/yr)	MAINTEN-ANCE ($/mi/yr)	TOTAL COSTS ($/mi/yr)
60/400M/STG/100/35/11/M	23	13.4	1704	98040	10563	15228	752	26543
60/400M/STG/100/40/11/M	24	13.8	1704	120960	13084	15228	752	29043
60/400M/STG/100/45/11/M	25	13.8	1704	120960	13084	15228	752	29043

(1) Energy Use: This is calculated by multiplying the average yearly burn time (4095 hr/yr.) times the wattage of the lamp (kw) which yields the energy use in kwh/yr.
(2) Annual Energy: Annual cost of energy per year.
(3) Initial Cost Total: includes initial cost of poles, luminaires, and wiring.
(4) Initial Cost Annual: amortized value over the life of the item for poles, luminaires, and wiring. (Poles and luminaires = 20 years, aerial = 25 years, underground = 35 years).
(5) Total Energy Annual: Total Annual cost of energy as described in Section 6.2.6.
(6) Total Cost Annual: the sum of the initial cost annual (luminaires, poles, and wiring), total energy annual and total maintenance annual.

NOTE: All costs are based on 1976 cost data, and calculated for a 1 mile stretch of roadway on that particular system.

in Table 19. Similarly, using the lighting cost data described in Section 6, the elements of Table 22 of Appendix A of the Design Guide were constructed for each new lighting system configuration. Only metal poles were considered in all cost calculations. A sample is illustrated in Table 20.

Benefit data was developed from the regression equation:

$$AR = 3.61 + 7.85AT + .000164PD - .532VI15$$

where

AR = Accident rate per 10,000 vehicle miles
AT = Area type = 1 for CBD
                 = 0 for other
PD = Population density: persons per square mile (per 2.56 square kilometers)
$VI15$ = 15th percentile visibility

Accident costs (AC) for a given combination of area type, population density and visibility is determined from the equation:

$$AC = AR \times Average\ cost\ per\ accident$$

and accident benefits (B) from the equation

$$B = AC\ (at\ VI15 = 1) - AC\ (at\ VI15 \geq 1)$$

A basic assumption is that no lighted site will have a visibility less than 1 (moonlight) the worst condition (6), and thus all benefits are computed based on a change in accident rate from $VI15 = 1$.

Although area type enters the regression equation and results in different accident rates and accident costs for CBD vs other type of sites, it has no effect on benefits (it is subtracted out in the last equation above). The entries in Table 21 are thus the same for both CBD and Other site types. It is included in the analysis for completeness.

Population density also has no effect until it (in combination with VI15) causes AR to be reduced to zero (see Table 21, Column #7, entry corresponding, to $VI15 = 10$).

VI15 for values greater than 15, is assumed to increase only slightly rather than following the regression equation for $VI15 > 15$ (93% of optimum at $VI15 = 15$ up to 100% of optimum at $VI15 = 50$) based on (1) the results of Gallagher (1) which showed a distinct asymptotic relationship for high VI and (2) Lack of field data with measured VI15 greater than 15. This implies a conservative approximation of potential accident reduction at high visibility levels.

72.

Table 21. Benefits of New Systems

VI$_{15}$	CBD						OTHER					
Density →	10,000	20,000	30,000	40,000	50,000	60,000	10,000	20,000	30,000	40,000	50,000	60,000
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1129	1129	1129	1129	1129	1129	1129	1129	1129	1129	1129	1129
3	2280	2280	2280	2280	2280	2280	2280	2280	2280	2280	2280	2280
4	3409	3409	3409	3409	3409	3409	3409	3409	3409	3409	3409	3409
5	4538	4538	4538	4538	4538	4538	4538	4538	4538	4538	4538	4538
6	5667	5667	5667	5667	5667	5667	5667	5667	5667	5667	5667	5667
7	6796	6796	6796	6796	6796	6796	6796	6796	6796	6796	6796	6796
8	7947	7947	7947	7947	7947	7947	7947	7947	7947	7947	7947	7947
9	9076	9076	9076	9076	9076	9076	9076	9076	9076	9076	9076	9076
10	10205	10205	10205	10205	10205	10205	10054	10205	10205	10205	10205	10205
11	11337	11337	11337	11337	11337	11337	10054	11337	11337	11337	11337	11337
12	12471	12471	12471	12471	12471	12471	10054	12471	12471	12471	12471	12471
13	13604	13604	13604	13604	13604	13604	10054	13549	13604	13604	13604	13604
14	14738	14738	14738	14738	14738	14738	10054	13549	14738	14738	14738	14738
15	15870	15870	15870	15870	15870	15870	10054	13549	15870	15870	15870	15870

APPLY FACTOR FOR VOLUME CHANGE

5,000	10,000	15,000	20,000	25,000
0.5	1.0	1.5	2.0	2.5

* = Density in people per square mile

BENEFITS(B) for VI15>15 = B(VI15=15)(1−0.002xΔVI15)

From this point on, certain assumptions must be made about popula-
tion density and traffic volume, otherwise the number of combinations
becomes unmanageable.* To simplify the analysis only a population
density of 30,000 persons per square mile (11,700 persons per square
kilometer) and a traffic volume of 20,000 VPD will be employed. ** All
other combinations can then be obtained using the appropriate multipliers
described in the footnotes to the tables.

Benefit/cost ratios were developed by combining the data in Tables
20 and 21. Only those systems with a B/C ratio of at least 1 would be
included in Table 23 of Appendix A of the Design Guide, which presents
the results of the economic analysis and includes the system description,
VI15 area, density, volume and benefit-cost ratio. A sample is illus-
trated in Table 22. It must be noted that this analysis if based on only
one pavement surface. Other combinations of lighting, geometry and
surface type can be analyzed using the methods outlined in the Design Guide.

7.1.3 Optimization Analysis

Up to this point, no restrictions were made on the selection of
lighting systems except that the benefit-cost ratio be greater than 1.
At this point, four constraints were considered in the analysis.

1. Design
2. Visibility or Accident
3. Economic
4. Energy

Design Constraints

Design constraints are merely pre-selection (or deletion) of certain
types of hardware or design features. Their effect is to limit the total
number of possibilities based on user preference or availability of
specific types of equipment. Examples are presented subsequently.

Visibility Constraints

The first type of visibility constraint is a minimum acceptable
VI15. This constraint is based on providing some minimum level of visi-
bility. This type of constraint implies some maximum predicted accident
rate that is acceptable. All lighting designs which do not meet this
VI15 constraint are deleted from further analysis. Only those systems
with

(1) VI15 greater than or equal to a minimum acceptable VI15 and
(2) B/C greater than or equal to 1

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* Note: 5 volumes x 6 densities x about 400 lighting combinations =
         12,000 Total Possibilities.
** These values of volume and density are the nearest to the averages
   for our sites.

74.

would be considered at this point in the analysis. It must be pointed out that the selection of a specific minimum acceptable VI15 is left to the user. He can base his choice on the data provided in Table 21 or on the results of Gallagher (1) which related visibility and driver performance.

A second type of visibility constraint would be to select optimum designs based on maximizing the VI15 and hence maximizing the predicted accident reduction potential. Examples are provided at the end of this section. For a more complete discussion, oriented toward the prospective user, see the Design Guide.

Economic Constraints

The typical constraint in this case is a limited municipal budget whether for initial capital outlay or for annual costs. Solutions to this are of two types:

(1) Only fund some of the systems within the budget limitations.
(2) Design for a lower VI15, so that more (or even all) of the systems can be funded.

The actual decision is based on a municipality's priorities which is beyond the scope of this research. Examples are presented at the end of this section. More detail for the prospective user is presented in the Design Guide.

Energy Constraints

Energy in this context is treated as a non-economic resource. The decision to impose a restraint on the design of new systems is based on availability rather than cost. Optimization would be in terms of the most energy efficient design for those systems having B/C greater than or equal to 1. Examples are presented subsequently. The effect of energy constraints on visibility and accidents is discussed in Section 7.3.

7.1.4 Examples of Optimization

All of the necessary input data is presented in Table 70 of Appendix D. A sample is illustrated in Table 23.

The variables were described in Table 18 of this section. Those that are incremented by the computer program for each road surface/width combination include:

        Arrangement (1-sided near, 2-sided staggered and opposite)
        Spacing (100' - 250' in 50' increments;
              30.5 - 76.2m in 15.2m increments)

Table 22 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI$_{15}$	COSTS ($/mi/yr)	AREA (TYPE)	DENSITY (People/ sq mi)	VOLUME (ADT)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
60/400M/STG/100/35/11/M	23	13.4	26543		30000	20000	27208	1.03
60/400M/STG/100/40/11/M	24	13.8	29043		30000	20000	29476	1.02
60/400M/STG/100/45/11/M	25	13.8	29043		30000	20000	29476	1.02

(1) 11,7000 persons per square kilometer

Table 23 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI$_{15}$	ENERGY USE (Kwh/mi/ yr) x10^2	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)			TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq. mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN- TENANCE	ENERGY x10^2								
60/400M/STG/100/35/11/M	23	13.4	1704	98040	10563	752	15228	26543	CBD	30000	20000	40	27208	1.03
60/400M/STG/100/40/11/M	24	13.8	1704	120960	13084	752	15228	29043	CBD	30000	20000	44	29476	1.02
60/400M/STG/100/45/11/M	25	13.8	1704	120960	13084	752	15228	29043	CBD	30000	20000	44	49476	1.02

Mounting Height (20' - 45' in 5' increments;
6.1 - 13.7m in 1.5m increments)*
Luminaire (400 and 150 HPS; 400 and 175 Mercury)

Four road conditions will be considered

CBD - 60' (18.3m) road width - 2 traffic directions
CBD - 30' (9.1m) road width - 1 traffic direction
Other - 60' (18.3m) road width - 2 traffic directions
Other - 30' (9.1m) road width - 1 traffic direction

Since accident benefits are the same for both "CBD" and "Other" sites at the population densities utilized the cases discussed below are applicable to both types of sites.

Case I - No Constraints

The 2 entries in Table 24 below illustrate the optimum designs for each of the 2 road conditions. Each selection is based on maximizing the Benefit-cost ratio.

Table 24. Optimum Designs - No Constraints

Item No.	Con-Straint	Road Conditions*	Optimum Design (Case #)	System Code	Benefit/Cost Ratio
1	None	60'	139	60/400H/STG/200/40/11M[1]	1.63
2	None	30'	160	30/400H/SS/150/45/5/M	2.64

(1) Multiple Choices
* 1 ft. = 0.3m

Case II - Design Constraints

Constraint 1: Use only (a) 400M
(b) 175M
(c) 400HPS
(d) 150HPS

78.

For each of the above 4 design constraints the search of Table 70 is made separately for each lamp type. Items 1-8 of Table 25 illustrate the optimum designs for each of the 2 road conditions. It can be seen that except for 175 mercury on 60' (18.3m) roadways, it is always possible to design a cost-beneficial lighting system with any of the lighting sources under the chosen population density/traffic volume/road surface conditions.

Table 25. Optimum Designs - Design Constraints

Item No.	Constraint	Road Conditions*	Optimum Design (Case #)	System Code	Benefit/ Cost Ratio
1	400M only	60'	30	60/400H/STG/150/45/11/M	1.07
2	400M only	30'	100	30/400M/STG/200/45/5/M	1.47
3	175M only	60'	None exists with B/C $\geq$ 1		
4	175M only	30'	364	30/175M/SS/100/35/5/M	1.51
5	400H only	60'	139	60/400H/STG/200/40/11/M [1]	1.63
6	400H only	30'	160	30/400H/SS/150/45/5/M	2.64
7	150H only	60'	214	60/150H/OPP/100/35/11/M [1]	1.51
8	150H only	30'	308	30/150H/STG/200/30/5/M	2.41
9	HPS and STG	60'	139	60/400H/STG/200/40/11/M [1]	1.63
10	HPS and STG	30'	308	30/150H/STG/200/30/5/M	2.41

(1) Multiple Choices

*1 ft. = 0.3M

Constraint 2: Using only HPS in a staggered arrangement.

Items 9 and 10 of Table 25 illustrate the optimum designs for each of the 2 road conditions.

Case III Visibility Constraints

Constraint 1: Minimum acceptable VI15 greater than or equal to 15.*

With this type of constraint, the optimum design is that system with VI15 $\geq$15 with maximum benefit-cost ratio. Table 70 is first searched on column 3 for those systems that will exceed the VI15 constraint. Then the one with maximum B/C ratio is selected. Items 1 and 2 of Table 26 illustrate the optimum designs.

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* 93% of optimum performance based on the results of Gallagher. (Ref. 1)

Constraint 2: Maximum VI15

In this case, that system with maximum VI15 with benefit-cost ratio greater than or equal to 1 is selected. Items 3 and 4 of Table 26 illustrate the optimum designs.

Table 26. Optimum Designs - Visibility Constraints

Item No.	Constraint	Road Conditions*	Optimum Design (Case #)	System Code	Benefit/ Cost Ratio	Other
1	Min VI15 ≥ 15	60'	135	60/400H/STG/150/45/11/M	1.43	
2	Min VI15 ≥ 15	30'	210	30/400H/STG/250/45/5/M	2.23	
3	Maximum VI15	60'	127	60/400H/STG/100/30/11/M	1.10	VI15 = 19.1
4	Maximum VI15	30'	192	30/400H/STG/100/30/5/M	1.12	VI15 = 28.7

* 1 ft. = 0.3m

Case IV Economic Constraints

Constraint 1 - Initial investment less than $50,000.

In this case, the only solutions are those lighting systems with initial costs less than $50,000. The optimum designs would be those with maximum benefit-cost ratios. Items 1 and 2 of Table 27 provide the solutions.

Constraint 2: Total annual expenditures less than $10,000.

In this case, only systems with total annual costs (including initial, maintenance and energy) less than $10,000 are solutions. The optimum designs are those with maximum benefit-cost ratio. Items 3 and 4 of Table 27 are the optimum designs.

Table 27. Optimum Designs - Economic Constraints

Item No.	Constraint	Road Conditions*	Optimum Design (Case #)	System Code	Benefit/ Cost Ratio	Other
1	Initial Investment ≤ $50,000/ mile	60'	250	60/150H/STG/250/40/11/M	1.37	Initial Costs = 49,331
2	Initial Investment ≤ $50,000/ mile	30'	160	30/400H/SS/150/45/5/M	2.64	Initial Costs = 45,003
3	Total Annual Costs ≤ $10,000 mile	60'	250	60/150H/STG/250/40/11/M	1.37	Annual Costs = $9949
4	Total Annual Costs ≤ $10,000/ mile	30'	165	30/400H/SS/200/45/5/M	2.44	Annual Costs = $8359

*1 ft. = 0.3m

Case V Energy Constraints

As mentioned earlier, energy is treated as a non-economic resource.

Constraint 1: Total Annual Energy Use less than 10^6 kwh.

The optimum design would be that system having maximum benefit-cost
ratio with energy use less than 10^6 kwh. Items 1 and 2 of Table 27 pro-
vide the optimum designs.

Constraint 2: Minimum Energy Use

In this case, that system with minimum energy use having benefit-
cost ratio greater than or equal to 1 is the optimum design. Items 3
and 4 of Table 28 illustrate the solution.

Table 28. Optimum Designs - Energy Constraints

Item No.	Constraint	Road Conditions*	Optimum Design (Case #)	System Code	Benefit/ Cost Ratio	Other
1	Total Energy Use $\leq 10^6$ kwhr/ mile	60'	139	60/400H/STG/200/40/11/M	1.63	Annual energy use= $.852 \times 10^5$
2	Total Energy Use $\leq 10^6$ kwhr/ mile	30'	160	30/400H/SS/150/45/5/M	2.64	Annual energy use = $.573 \times 10^5$ kwhr
3	Minimum Energy Use	60'	225	60/150H/OPP/200/40/11/M	1.16	Annual energy use = $.319 \times 10^5$ kwhr
4	Minimum Energy Use	30'	273	30/150H/SS/250/30/5/M	1.55	Annual energy use = $.129 \times 10^5$ kwhr

* 1 ft. = 0.3M

Case VI: Combinations of Constraints

Combinations of constraints can be employed in selecting optimum
designs. The optimum is that design (if any) meeting all of the con-
straints.

Case 1. Use only HPS
         VI15 $\geq$15
         Total initial investment less than $50,000
         Total Annual Energy Use less than 10^6 kwhr

There are no optimum designs for each of the 2 roadway conditions,
as illustrated in Table 29.

Case 2. Same as above but VI15 greater than 10*
Case 3   Same as above but no VI15 constraint (60' (18.3m) road only)
Items 3-5 of Table 29 illustrate the optimum designs.

* 85% of maximum performance (Ref. 1)

81.

Table 29. Optimum Designs - Combination of Constraints

Item No.	Constraint	Road Conditions*	Optimum Design (Case#)	System Code	Benefit/ Cost Ratio	Other
1	Combination I (see Text)	60'	None			
2	Combination I (see Text)	30'	None			
3	Combination II (see Text)	60'	None			
4	Combination II (see Text)	30'	160	30/400H/SS/150/45/5/M	2.64	VI15 = 13.5 Initial Costs = $45,003 Annual energy use = .573x10^6 kwh
5	Combination III (For 60' only)	60'	250	60/150H/STG/40/11/M	1.37	Initial Cost = $49,331 Annual energy use = .258x10^6 kwh

* 1 ft. = 0.3m

Case VII Accident Reduction Constraints

This type of constraint is dependent on area type, hence is illustrated separately.

To derive "Other" accident reduction figures (all other related items are the same) multiply the accident reduction for CBD by 1.98. For other combinations of volumes and population density, the values below provide the correct multipliers.

Population Density* (persons per square mile)

VI15	10,000	20,000	30,000	40,000	50,000	60,000
1-9	2.66	2.23	1.98	1.81	1.70	1.61
10	2.62	2.23	1.98	1.81	1.70	1.61
11	2.36	2.23	1.98	1.81	1.70	1.61
12	2.15	2.23	1.98	1.81	1.70	1.61
13	1.97	2.22	1.98	1.81	1.70	1.61
14	1.82	2.05	1.98	1.81	1.70	1.61
15	1.69	1.91	1.98	1.81	1.70	1.61

Note: 1 square mile = 2.56 square kilometers

* Volume Correction (For other than 10,000 VPD) see Footnote of Table 21.

Case I. Reduce Accidents by 25%

In this case, the optimum solution is that design with maximum benefit-cost ratio that reduces accidents by at least 25%. Items #1 and 2 of Table 30 illustrate the optimum designs for CBD areas and Items #3 and 4 for other area types.

Table 30. Optimum Designs - Accident Constraints

ITEM NO.	CONSTRAINT	ROADWAY CONDITION	OPTIMUM DESIGN (CASE #)	SYSTEM DESCRIPTION	BENEFIT-COST RATIO	ACCIDENT REDUCTION
1	25% Reduction	CBD/60' width	139	60/400H/STG/200/4 and 11/M	1.63	40%
2	25% Reduction	CBD/30' width	160	30/400H/SS/150/45/5/M	2.64	44%
3	25% Reduction	Other/60' width	139	60/400H/STG/200/40/11/M	1.63	79%
4	25% Reduction	Other/30' width	160	30/400H/SS/150/45/5/M	2.64	87%
5	Maximum Reduction	CBD/60' width	135[1]	60/400H/STG/150/45/11/M	1.43	47%
6	Maximum Reduction	CBD/30' width	192	30/400H/STG/100/30/5/M	1.12	49%
7	Maximum Reduction	Other/60' width	135	60/400H/STG/150/45/11/M	1.43	93%
8	Maximum Reduction	Other/30' width	192	30/400H/STG/100/30/5/M	1.12	97%

1 ft. = 0.3m

(1) Multiple choices. Case 135 has maximum B/C ratio

Case II. Maximum Accident Reduction

In this case, the optimum solution is that design with maximum accident reduction potential. Items #5 and 6 of Table 30 illustrate the solutions for CBD areas while Items #7 and 8 illustrate the solutions for other area types.

7.2 UPGRADED SYSTEMS

7.2.1 Variables

Table 11 listed all combinations of variables that were employed in these analyses. As in Section 7.1.1, all combinations of variables were analyzed using the VI computer program to determine VI15.

83.

7.2.2 Upgrade Options

There are a multitude of options available to the lighting engineer to provide an upgraded lighting system with improved visibility. They can be as simple as lamp or luminaire replacement or as complex as complete re-design of the lighting systems in terms of spacing, mounting height, arrangement, overhang, luminaire type and even re-surfacing of the roadway. It is not the objective of this analysis to cover every possible upgrading, but only to specify a fixed number of existing conditions and then apply the economic methodology to those conditions in order to obtain optimal upgraded systems.

For this analysis only the following existing conditions will be studied:

      (a)   CBD/60' (18.3m) width/2 traffic directions/400 Mercury/
             30' (9.1m) Mounting Height/200' (61.0m) spacing/staggered.

      (b)   CBD/30' (9.1m) width/1 traffic direction/400 Mercury/
             30' (9.1m) Mounting Height/200' (61.0m) spacing/1-sided.

      (c)   Other/60' (18.3m) width/2-traffic directions/400 Mercury/
             30' (9.1m) Mounting Height/200' (61.m) spacing/opposite.

      (d)   Other/30' (9.1m) width/1-traffic direction 175 Mercury/
             25' (7.6m) Mounting Height/200' (61.0m) spacing/1-sided.

The upgraded systems that will be considered inlcude:

For Case (a)

     1.   400M $\longrightarrow$ 400H
     2.   400M $\longrightarrow$ 150H
     3.   200' (61.0m) spacing $\longrightarrow$ 100' (30.5m) spacing
     4.   Combination of 1 and 3
     5.   Combination of 2 and 3

For Case (b)

     1.   400M $\longrightarrow$ 400H
     2.   400M $\longrightarrow$ 150H
     3.   200' (61.0m) spacing $\longrightarrow$ 100' (30.5m) spacing
     4.   Combination of 1 and 3
     5.   Combination of 2 and 3

For Case (c)

       1.   400M ⟶ 400H
       2.   400M ⟶ 150H
       3.   200' (61.0m) spacing ⟶ 100' (30.5m) spacing
       4.   Combination of 1 and 3
       5.   Combination of 2 and 3

For Case (d)

       1.   175M ⟶ 150H
       2.   200' (61.0m) spacing ⟶ 100' (30.5m) spacing
       3.   Combination of 1 and 2
       4.   25' (7.6m) Mounting Height ⟶ 30' (9.1m) Mounting Height
       5.   Combination of 1 and 4

In this latter case, we assume wood poles exist hence the mounting height can be changed at reasonable cost.

7.2.3 Economic Analysis

Using the VI program, the data in Table 19, the combination of variables in Table 18, the upgrade options listed above and the lighting cost data of Section 6, the elements of Table 31 were developed for each possible upgrade.

Benefit and benefit-cost data were developed following the same procedures as in Section 7.1.2 except that the equation for Benefits was

B = AC (at existing VI15) - AC (at new VI15) and AC is derived from

AC = AR x Average cost per accident

where AR = accident rate as determined from the regression equation of Section 5, and average costs found in Section 5.

The same assumptions as described in Section 7.1.2 will be applied here: Population Density of 30,000 persons per square mile (11,700 persons per square kilometer) and traffic volume of 20,000 VPD.

85.

Table 31. Costs of Upgraded Systems

EXISTING SYSTEM:

Code 60/400M/STG/200/30/11/M

Case No. 32

VI_{15} 4.6

Energy Use 852 $\times 10^2$

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mile/yr) ($\times 10^2$)	Initial Costs		Annual Costs ($/mi/yr)		Total Annual Costs ($/mi/yr)
				Total ($/mi/yr)	Annual ($/mi/yr)	Energy	Mainten-ance	
60/400H/STG/200/30/11/M	137	8.2	852	10660	1172	0	951	2123
60/150H/STG/200/30/11/M	243	6.3	319	10660	1172	-1440	951	683
60/400M/0PP/100/30/11/M	2	9.4	1704	46429	5107	2303	398	7808
60/400H/0PP/100/30/11/M	107	17.7	1704	59371	6530	2303	2150	10983
60/150H/0PP/100/30/11/M	213	13.2	639	59371	6530	- 672	2150	8008

Table 31. Costs of Upgraded Systems (Cont.)

EXISTING SYSTEM:

Code 60/400M/OPP/200/30/11/M VI_{15} 2.0

Case No. 12   Energy Use 852×10^2

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mile/yr) ($\times 10^2$)	Initial Costs		Annual Costs ($/mi/yr)		Total Annual Costs ($/mi/yr)
				Total ($/mi/yr)	Annual ($/mi/yr)	Energy	Mainten- ance	
60/400H/OPP/200/30/11/M	117	3.0	852	10660	1172	0	951	2123
60/150H/OPP/200/301/11/M	223	4.2	319	10660	1172	-1440	951	683
60/400M/OPP/100/30/11/M	2	9.4	1704	46429	5107	2303	398	7808
60/400H/OPP/100/30/11/M	107	17.7	1704	59371	6530	2303	2150	10983
60/150H/OPP/100/30/11/M	213	13.2	639	59371	6530	-672	2150	8008

Table 31. Costs of Upgraded Systems (Cont.)

EXISTING SYSTEM:

Code 30/400M/SS/200/30/5/M

Case No. 57

VI_{15} 2.0

Energy Use 426 $\times 10^2$

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mile/yr) ($\times 10^2$)	Initial Costs		Annual Costs ($/mi/yr)		Total Annual Costs ($/mi/yr)
				Total ($/mi/yr)	Annual ($/mi/yr)	Energy	Maintenance	
30/400H/SS/200/30/5/M	162	4.3	426	5330	586	0	475	1061
30/150H/SS/200/30/5/M	268	4.8	160	5330	586	-720	475	341
30/400M/SS/100/30/5/M	47	7.4	852	23214	2554	1152	199	3905
30/400H/SS/100/30/5/M	152	15.0	852	29685	3265	1152	1075	5492
30/150H/SS/100/30/5/M	258	10.7	319	29685	3265	-336	1075	4004

88.

Table 31. Costs of Upgraded Systems (Cont.)

EXISTING SYSTEM:

Code 30/175M/SS/200/25/5/W

Case No. 372

VI_{15} 1.3

Energy Use 186 x10^2

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mile/yr) (x 10^2)	Initial Costs		Annual Costs ($/mi/yr)		Total Annual Costs ($/mi/yr)
				Total ($/mi/yr)	Annual ($/mi/yr)	Energy	Mainten-ance	
30/150H/SS/200/25/5/W	267	3.2	160	5330	586	-72	475	989
30/175M/SS/100/25/5/W	362	4.6	372	16155	1776	504	199	2479
30/150H/SS/100/25/5/W	257	8.6	319	23226	2488	311	898	3697
30/175M/SS/100/30/5/W	373	1.9	186	780	86	0	0	86
30/150H/SS/100/30/5/W	268	4.8	160	6110	672	-72	470	1075

Table 32 presents all relevant data for the economic analysis. This includes:

(1) Existing System Description (From Top of Table 31)
(2) Area Type, density and volume (Fixed)
(3) Case Number (From Table 31, Column 2)
(4) Upgrade Options (From Table 31, Column 1)
(5) VI15 (From Table 31, Column 3)
(6) Energy Use (From Table 31, Column 4)
(7) % Reduction in Energy (see discussion below)
(8) Increase Total Annual Cost (Table 31, Column 9)
(9) Accident Reduction (see discussion below)
(10) Benefits (see discussion below)
(11) Benefit-Cost ratio (#10 divided by #8)

Percent reduction in energy use (RE) - Item (7) above is computed using the equation:

$$RE = \frac{\text{energy use at existing VI15} - \text{energy use at new VI15}}{\text{energy use at existing VI15}}$$

A negative value for RE indicates an increase in energy use.

Accident Reduction (ACR) - Item 9 above - is computed based on the regression equation derived in Section 5. This equation provides Accident Rate (AR) per 10,000 vehicle miles as a function of visibility, population density and area type as follows

$$AR = 3.61 + 7.85 \text{ (CBD vs Other)} \times .000164 \text{ (Density)} - .532 \text{ (VI15)}$$

To compute (ACR) the following equation is employed.

$$ACR = \frac{\text{AR (at Existing VI15)} - \text{AR (at New VI15)}}{\text{AR at (Exsiting VI15)}} \qquad \text{for VI15} \leq 15$$

$$= \frac{\text{AR (at Existing VI15)} - \text{AR (at VI15=15)} (1-.002\Delta VI15)}{\text{AR (at Existing VI15)}} \text{ for VI15} > 15$$

where $\Delta VI15$ = VI15 (at new VI15) - 15

Benefits - Item 10 above - are also computed from the regression equation as follows

$$B = [\text{AR (at Existing VI15)} - \text{AR (at New VI15)}] \times \text{Average cost per accident}$$

7.2.4 Optimization Analysis

The description of this analysis was presented in Section 7.1.3. The same constraints will be applied here: design, visibility, economic and energy. All pertinent data is presented in Table 32.

Table 32. Summary of Upgraded Systems

EXISTING SYSTEM

Code 60/400M/STG/200/30/11/M VI_{15} 4.6

Case No. 32   Energy Use 852 x 10^2

Area Type CBD   Density 30,000   Volume 20,000

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mi/yr) (x 10^2)	Reduction in Energy (%)	Increased Total Annual Costs ($/mi/yr)	Accident Reduction (%)	Benefits ($/mi/yr)	Benefit Cost Ratio
60/400H/STG/200/30/11/M	137	8.2	852	0	2123	12	3409	1.61
60/150H/STG/200/30/11/M	243	6.3	319	63	683	4	1129	1.65
60/400M/OPP/100/30/11/M	2	9.4	1704	-100	7808	16	4538	0.58
60/400H/OPP/100/30/11/M	107	17.7	1704	-100	10983	39	9092	0.83
60/150H/OPP/100/30/11/M	213	13.2	639	25	8008	31	9011	1.13

Table 32. Summary of Upgraded Systems (Cont.)

EXISTING SYSTEM

Code   30/400M/SS/200/30/5/M VI_{15} 2.0

Case No.   57   Energy Use 426×10^2

Area Type   CBD   Density   30,000   Volume   20,000

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mi/yr) ($\times 10^2$)	Reduction in Energy (%)	Increased Total Annual Costs ($/mi/yr)	Accident Reduction (%)	Benefits ($/mi/yr)	Benefit Cost Ratio
30/400H/SS/200/30/5/M	162	4.3	426	0	1061	7	2280	2.15
30/150H/SS/200/30/5/M	268	4.8	160	62	341	10	3409	10.00
30/400M/SS/100/30/5/M	47	7.4	852	-100	3905	17	5667	1.45
30/400H/SS/100/30/5/M	152	15.0	852	-100	5492	45	14741	2.68
30/150H/SS/100/30/5/M	258	10.7	319	25	4004	31	10208	2.55

92.

Table 32. Summary of Upgraded Systems (Cont.)

EXISTING SYSTEM

Code 60/400M/0PP/200/30/11/M VI_{15} 2.0

Case No. 12   Energy Use 852×10^2

Area Type Other   Density 30,000   Volume 20,000

Upgrade Options (System Code)	Case No.	VI_{15}	Energy Use (Kwh/mi/yr) ($\times 10^2$)	Reduction in Energy (%)	Increased Total Annual Costs ($/mi/yr)	Accident Reduction (%)	Benefits ($/mi/yr)	Benefit Cost Ratio
60/400H/0PP/200/30/11/M	117		852	0	2123	7	1151	0.54
60/150H/0PP/200/30/11/M	223		319	63	683	14	2280	3.39
60/400M/0PP/100/30/11/M	2		1704	-100	7808	50	7947	1.02
60/400H/0PP/100/30/11/M	107		1704	-100	10983	93	12501	1.14
60/150H/0PP/100/30/11/M	213		639	25	8008	78	12420	1.55

93.

Table 32. Summary of Upgraded Systems (Cont.)

EXISTING SYSTEM

Code 30/175M/SS/200/25/5/W   VI$_{15}$ 1.3

Case No. 372   Energy Use 186

Area Type Other   Density 30,000   Volume 20,000

Upgrade Options (System Code)	Case No.	VI$_{15}$	Energy Use (Kwh/mi/yr) ($\times 10^2$)	Reduction in Energy (%)	Increased Total Annual Costs ($/mi/yr)	Accident Reduction (%)	Benefits ($/mi/yr)	Benefit Cost Ratio
30/150H/SS/200/25/5/W	267	3.2	160	14	989	13	2280	2.31
30/175M/SS/100/25/5/W	362	4.6	373	-100	2479	33	4538	1.83
30/150H/SS/100/25/5/W	257	8.6	319	-72	3697	53	9076	2.45
30/175M/SS/200/30/5/W	373	1.9	186	0	86	7	1129	13.13
30/150H/SS/200/30/5/W	268	4.8	160	14	1075	33	4538	4.22

7.2.5 Examples of Optimization

The variables employed were presented in Table 19. The upgraded options were described in Section 7.2.2 This section will present optimums for various sets of constraints.

Case I - No Constraints

Items 1-4 of Table 33 present the optimum designs for each of the 4 basic input conditions with no constraints on the designs. They are obtained by searching the last column of Table 32 for the highest B/C ratio.

Table 33. Optimum Designs

Item No.	Constraint	Road Condition	Existing System	(Case #)	Optimum Designs	(Case #)	Benefit-Cost Ratio
1	None	CBD/60'	60/400M/STG/200/30/11/M	(32)	60/150H/STG/200/30/11/M	(243)	1.65
2	None	CBD/30'	30/400M/SS/200/30/5/M	(57)	30/150H/SS/200/30/5/M	(268)	10.0
3	None	Other/60'	60/400M/OPP/200/30/11/M	(12)	60/150H/OPP/200/30/5/M	(223)	3.39
4	None	Other/30'	30/175M/SS/200/25/5/M	(372)	30/175M/SS/200/30/5/W	(373)	13.13

Case II - Design Constraints

Constraint 1. Use only Mercury lamps
Constraint 2. Use only HPS lamps

Items 1-4 and 5-8 of Table 34 illustrate the optimum designs for each of the above two designs constraints. The search of Table 32 is made separately for each lamp type.

Table 34. Optimum Designs - Design Constraints

Item No.	Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit-Cost Ratio
1	Only mercury	CBD/60'	(32)	Existing system	(32)	
2	Only mercury	CBD/30'	(57)	30/400M/SS/100/30/5/M	(47)	1.45
3	Only mercury	Other/60'	(12)	60/400M/OPP/100/30/11/M	(2)	1.02
4	Only mercury	Other/30'	(372)	30/175M/SS/200/30/5/W	(373)	13.13
5	Only HPS	CBD/60'	(32)	60/150H/STG/200/30/11/M	(243)	1.65
6	Only HPS	CBD/30'	(57)	30/150H/SS/200/30/5/M	(268)	10.0
7	Only HPS	Other/60'	(12)	60/150H/OPP/200/30/5/M	(223)	3.39
8	Only HPS	Other/30'	(372)	30/150H/SS/200/30/5/W	(268)	4.22

95.

Case III - Visibility Constraints

Constraint 1. VI15 greater than or equal to 10
Constraint 2. Maximum Visibility

Items 1-4 and 5-8 of Table 35 provide optimum designs for each of
the above two visibility constraints. These are identified by first
locating the system in Table 32 that meet the VI15 constraint, then
selecting the one with highest B/C ratio. For case 4 - 30' road, other
area type, there is no design that has benefit-cost ratio $\geq$ 1 except for
the existing system.

Table 35. Optimum Designs - Visibility Constraints

Item No.	Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit- Cost Ratio	Other
1	VI15$\geq$10	CBD/60'	(32)	60/150H/OPP/100/30/11/M	(213)	1.13	
2	VI15$\geq$10	CBD/30'	(57)	30/400H/SS/100/30/5/M	(152)	2.68	
3	VI15$\geq$10	Other/60'	(12)	60/150H/OPP/100/30/11/M	(243)	1.55	
4	VI15$\geq$10	Other/30'	(372)	None available			
5	Maximum VI15	CBD/60'	(32)	60/150H/OPP/100/30/11/M	(243)	1.13	VI15=13.2
6	Maximum VI15	CBD/30'	(57)	30/400H/SS/100/30/5/M	(152)	2.68	VI15=15.0
7	Maximum VI15	Other/60'	(12)	60/400H/OPP/100/30/11/M	(107)	1.14	VI15=17.7
8	Maximum VI15	Other/30'	(372)	30/150H/SS/100/25/5/W	(257)	2.45	VI15=8.6

Case IV - Economic Constraints

Constraint 1. Initial costs less than $15000*
Constraint 2. Annual costs (Total) less than $1000
Constraint 3. Minimum costs

All 3 constraints result in the same optimum designs which are
illustrated by Items 1-4 of Table 36. They are identified by locating
the system meeting the constraint in Table 32 and then selecting the
one with highest B/C ratio 1.

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* See Table 31

Table 36. Optimum Designs - Economic Constraints

Item No.	Design Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit-Cost Ratio	Other
1	Initial Costs ≤ $15,000/mile (1)	CBD/60'	(32)	60/150H/STG/200/30/11/M	(243)	1.65	Initial Cost= $10,660
2	Initial Costs ≤ $15,000/mile (1)	CBD/60'	(57)	30/150H/SS/200/30/5/M	(268)	10.00	Initial Costs= $5330
3	Initial Costs ≤ $15,000/mile (1)	Other/60'	(12)	60/150H/OPP/200/30/11/M	(213)	3.39	Initial Costs= $10,660
4	Initial Costs ≤ $15,000/mile (1)	Other/30'	(372)	30/175M/SS/200/30/5/W	(373)	13.13	Initial Costs= $780

(1) Same 4 solutions for annual costs ≤ $1000/mile or minimum costs

Case V - Energy Constraints

Constraint 1.   Energy Use less than 0.5×10^5 Kwhr
Constraint 2.   Minimum Energy Use

Both constraints are met by the same optimum designs which are illustrated by Items 1-4 of Table 37. They are found by first locating the designs which meet the energy constraint in Table 32 and then finding the one with maximum B/C ratio.

Table 37. Optimum Designs - Energy Constraints

Item No.	Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit-Cost Ratio	Other
1	Energy Use ≤ 5×10^6 Kwh/mile (1)	CBD/60'	(32)	60/150H/STG/200/30/11/M	(243)	1.65	Annual energy use= $.319 \times 10^5$ Kwh
2	Energy use ≤ 5×10^6 Kwh/mile (1)	CBD/30'	(57)	30/150H/SS/200/30/5/M	(268)	10.00	Annual energy use= $.16 \times 10^5$ Kwh
3	Energy use ≤ 5×10^6 Kwh/mile (1)	Other/60'	(12)	60/150H/OPP/200/30/11/M	(223)	3.39	Annual energy use= $.319 \times 10^5$ Kwh
4	Energy use ≤ 5×10^6 Kwh/mile (1)	Other/30'	(372)	30/150H/SS/200/25/5/W	(267)	2.31	Annual energy use= $.16 \times 10^5$ Kwh

(1) Same solution for minimum energy use

Case VI - Accident Constraints

Constraint 1.   Reduce Accidents by 25%
Constraint 2.   Maximum accident reduction

For the first constraint, Items 1-4 of Table 38 provide optimum designs. For the second constraint, Items 5-8 of Table 31 provide optimum design. In both cases, the data in Column 7 of Table 32 locates the designs and the one with highest B/C ratio.

Table 38. Optimum Designs - Accident Constraint

Item No.	Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit-Cost Ratio	Other
1	Reduce Accidents 25%	CBD/60'	(32)	60/150H/OPP/100/30/11/M	(213)	1.13	Accident Reduction=31%
2	Reduce Accidents 25%	CBD/30"	(57)	30/400H/SS/100/30/5/M	(152)	2.68	Accident Reduction=45%
3	Reduce Accidents 25%	Other/60'	(12)	60/150H/OPP/100/30/11/M	(213)	1.55	Accident Reduction=78%
4	Reduce Accidents 25%	Other/30'	(372)	30/150H/SS/200/30/5/W	(268)	4.22	Accident Reduction=33%
5	Maximum Accident Reduction	CBD/60'	(32)	60/150H/OPP/100/30/11/M	(213)	1.13	Accident Reduction=31%
6	Maximum Accident Reduction	CBD/30'	(57)	30/400H/SS/100/30/5/M	(152)	2.68	Accident Reduction-45%
7	Maximum Accident Reduction	Other/60'	(12)	60/400H/OPP/100/30/11/M	(107)	1.14	Accident Reduction=93%
8	Maximum Accident Reduction	Other/30'	(372)	30/150H/SS/100/25/5/W	(257)	2.45	Accident Reduction=53%

Case VII - Combined Constraints

1. Constraint 1. VI15 greater than or equal to 10
    Constraint 2. Total annual costs less than $1000
    Constraint 3. Total Energy use less than 0.5×10^5 Kwhr
    Constraint 4. Accident Reduction of 25%.

For the combined constraints, no solution exists for any of the 4 roadway conditions.

2. Constraint 1. VI15 greater than or equal to 5*
    Constraint 2. Total annual costs less than $3500
    Constraint 3. Accident Reduction greater than 25%

Items 1-4 of Table 39 provide optimum designs for each of the 4 roadway conditions. Solutions are found by locating systems in Table 32 for each constraint separately and taking the solution (if any) with highest B/C ratio meeting every constraint.

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* 75% of maximum performance (Ref. 1)

98.

Table 39. Optimum Designs - Combined Constraints

Item No.	Constraint	Roadway Condition	Existing System	Optimum Designs	(Case #)	Benefit-Cost Ratio
1	Combined (See Text)	CBD/60'	(32)	60/150H/OPP/100/30/11/M	(213)	1.13
2	Combined (See Text)	CBD/30'	(57)	30/400H/SS/100/30/5/M	(152)	2.68
3	Combined (See Text)	Other/60'	(12)	60/150H/OPP/100/30/11/M	(213)	1.55
4	Combined (See Text)	Other/30"	(372)	30/150H/SS/100/25/5/W	(257)	2.45

7.3 REDUCED OR MORE EFFICIENT USE OF ENERGY

7.3.1 Introduction

As a result of recent energy shortages around the world and recent energy conservation programs, many communities are seeking ways to reduce their energy consumption. For roadway lighting, methods include:

(1) More efficient sources of illumination
(2) Reduction in the size of luminaires
(3) Reduction in the number of luminaires (i.e., turning off some luminaires
(4) More efficient combinations of spacings, arrangements, mounting heights
(5) Combination of the above as well as others.

However, before such changes are made, those responsible for system modifications should know what the impact of the proposed lighting changes will have on visibility and traffic safety. This section of the report will identify some of the available reduced energy options and determine their effect on visibility and traffic accidents. The analysis takes the form of the preceding Section 7.2.4 (Optimization of Upgraded Systems) with the only constraint being reduced energy.

7.3.2 Conditions to be Analyzed

Table 40 presents the conditions to be analyzed. There are 10 cases - 5 of CBD, 5 of Other; 2 road widths - 30' (9.1m) and 60' (18.3m) and 2 luminaires 400M and 175M. All sites have population densities of 30,000 persons per square mile (11,700 persons per square kilometer) and traffic volume of 20,000 V.P.D.

Table 40 - Conditions to be Analyzed

Case #	Area	Road Width(ft.)*	Luminaire	Arrangement	Spacing(ft.)*	Mounting Height(ft.)*
1	CBD	60	400M	Opposite	100	30
2	CBD	60	400M	Staggered	100	30
3	CBD	30	400M	Opposite	100	30
4	CBD	30	400M	Staggered	100	30
5	CBD	30	400M	1-sided	100	30
6	Other	60	400M	Opposite	100	30
7	Other	60	400M	Staggered	100	30
8	Other	30	175M	Staggered	100	30
9	Other	30	175M	1-sided	100	30
10	Other	30	175M	1-sided	50	30

* 1 ft. = 0.3m.

100.

7.3.3 Reduced Energy Options

There are four lighting design options that will be analyzed:

A. Changing the luminaire

    1. 400M to 400HPS
    2. 400M to 150HPS
    3. 175M to 150HPS

B. Changing the arrangement

    2 sided to 1-sided

C. Changing the Spacing (without removing the poles)

    100' (30.5m) to 200' (6.10m)

D. Combinations of the above.

Not all of the above apply to every configuration e.g., one cannot change a 100' (30.5m) staggered arrangement to one with a 200' (61.0m) staggered arrangement without either destroying the fundamental symmetry or moving existing poles - a costly change. Such changes were not considered.

7.3.4 Methodology

The analysis is the same as in Section 7.2 but with reduced energy being the only constraint. Table 41 illustrates the reduced energy options available as developed from the use of the FIRL data base. The data includes

    (1) Existing (From Table 19)
    (2) Reduced Energy Options (Specified above and Table 19)
    (3) Case Numbers (From Table 19)
    (4) Energy Use (new and change) (From Table 20)
    (5) VI15 (new and change) (From Table 19)
    (6) Site Characteristics (area, density and volume) - fixed
    (7) Accident Rates: new and change (Calculated as in Section 7.2)

With this table it is now possible, for given site/geometry/lighting conditions, to select energy-efficient upgrades and to determine their effect on accidents and visibility.

The fourth, fifth and sixth columns of Table 41 illustrate the energy use and changes while the last two columns illustrate the effect on accidents of reducing the energy. A negative number in columns five

Table 41 Reduced Energy Options

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) X10²	ENERGY CHANGE (Kwh/mi/yr) X10²	ENERGY CHANGE (%)	VI$_{15}$ UPGRADE	VI$_{15}$ CHANGE (%)	AREA TYPE	DENSITY (People/Sq. Mi.)	VOLUME (ADT)	ACCIDENTS NEW RATE (ac/mi/yr)	ACCIDENTS CHANGE (%)
60/400M/0PP/100/30/11/M	60/400M/0PP/30/11/M	2	1704	0	0	9.4	0	CBD	30000	20000	11.59	0
	60/150H/0PP/100/30/11/M	213	639	-1065	-63	13.2	40	CBD	30000	20000	9.46	-18
	60/400M/0PP/200/30/11/M	12	852	-852	-50	2.0	-79	CBD	30000	20000	15.32	32
	60/400H/0PP/200/30/11/M	117	852	-852	-50	3.0	-68	CBD	30000	20000	14.78	28
	60/150H/0PP/200/30/11/M	223	319	-1385	-81	4.2	-55	CBD	30000	20000	14.25	23
60/400M/STG/100/30/11/M	60/400M/STG/100/30/11/M	22	1704	0	0	12.4	0	CBD	30000	20000	9.99	0
	60/150H/STG/100/30/11/M	233	639	-1065	-63	13.1	6	CBD	30000	20000	9.46	-5
30/400M/0PP/100/30/5/M	30/400M/0PP/100/30/5/M	67	1704	0	0	12.8	0	CBD	30000	20000	9.46	0
	30/150H/0PP/100/30/5/M	278	639	-1065	-63	16.0	25	CBD	30000	20000	8.38	-11
	30/400M/0PP/200/30/5/M	77	852	-852	-50	3.1	-76	CBD	30000	20000	14.78	56

1 mile = 1.6 km
1 person/square mile = 0.4 persons/square kilometer

102.

Table 41 Reduced Energy Options (Continued)

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) x10^2	ENERGY CHANGE (Kwh/mi/yr) x10^2	ENERGY CHANGE (%)	VI_{15} UPGRADE	VI_{15} CHANGE (%)	AREA TYPE	DENSITY (People/Sq. Mi.)	VOLUME (ADT)	ACCIDENTS NEW RATE (ac/mi/yr)	ACCIDENTS CHANGE (%)
	30/400H/OPP/200/30/5/M	182	852	-852	-50	1.8	-86	CBD	30000	20000	15.32	62
	30/150H/OPP/200/30/5/M	288	319	-1385	-81	6.8	-47	CBD	30000	20000	12.66	34
30/400M/STG/100/30/5/M	30/400M/STG/100/30/5/M	87	1704	0	0	16.3	0	CBD	30000	20000	8.38	0
	30/150H/STG/100/30/5/M	298	639	-1065	-63	16.4	1	CBD	30000	20000	8.38	0
	30/400M/SS/100/30/5/M	47	852	-852	-50	7.4	-55	CBD	30000	20000	12.66	51
	30/400H/SS/100/30/5/M	152	852	-852	-50	15.0	-8	CBD	30000	20000	8.4	0
	30/150H/SS/100/30/5/M	258	319	-1385	-81	10.7	-34	CBD	30000	20000	10.53	26
30/400M/SS/100/30/5/M	30/400M/SS/100/30/5/M	47	852	0	0	7.4	0	CBD	30000	20000	12.66	0
	30/150H/SS/100/30/5/M	258	319	-533	-63	10.7	45	CBD	30000	20000	10.53	-17
	30/400M/SS/200/30/5/M	57	426	-426	-50	2.0	-73	CBD	30000	20000	15.32	21

Table 41 Reduced Energy Options   (Continued)

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) x10²	ENERGY CHANGE (Kwh/mi/yr) x10²	ENERGY CHANGE (%)	VI₁₅ UPGRADE	VI₁₅ CHANGE (%)	AREA TYPE	DENSITY (People/Sq. Mi.)	VOLUME (ADT)	ACCIDENTS NEW RATE (ac/mi/yr)	ACCIDENTS CHANGE (%)
	30/400H/SS/200/30/5/M	162	426	-426	-50	4.3	-42	CBD	30000	20000	14.25	13
	30/150H/SS/200/30/5/M	268	160	-692	-81	4.8	-35	CBD	30000	20000	13.72	8
60/400M/OPP/100/30/11/M	60/400M/OPP/100/30/11/M	2	1704	0	0	9.4	0	Other	30000	20000	3.74	0
	60/150H/OPP/100/30/11/M	213	639	-1065	-63	13.2	40	Other	30000	20000	1.61	-57
	60/400M/OPP/200/30/11/M	12	852	-852	-50	2.0	-79	Other	30000	20000	7.47	100
	60/400H/OPP/200/30/11/M	117	852	-852	-50	3.0	-68	Other	30000	20000	6.93	85
	60/150H/OPP/200/30/11/M	223	319	-1385	-81	4.2	-57	Other	30000	20000	6.40	71
60/400M/STG/100/30/11/M	60/400M/STG/100/30/11/M	22	1704	0	0	12.4	0	Other	30000	20000	2.15	0
	60/150H/STG/100/30/11/M	233	639	-1065	-63	13.1	6	Other	30000	20000	1.61	-25

104.

Table 41 Reduced Energy Options (Continued)

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) x10²	ENERGY CHANGE (Kwh/mi/yr) x10²	ENERGY CHANGE (%)	VI₁₅ UPGRADE	VI₁₅ CHANGE (%)	AREA TYPE	DENSITY (People/Sq. Mi.)	VOLUME (ADT)	ACCIDENTS NEW RATE (ac/mi/yr)	ACCIDENTS CHANGE (%)
30/175M/STG/100/30/5/M	30/175M/STG/100/30/5/M	403	746	0	0	8.9	0	Other	30000	20000	3.74	0
	30/150H/STG/100/30/5/M	298	639	-107	-14	16.4	84	Other	30000	20000	.55	-85
	30/175M/SS/100/30/5/M	363	373	-373	-50	6.4	-28	Other	30000	20000	5.34	43
	30/150H/SS/100/30/5/M	258	319	-427	-57	10.7	20	Other	30000	20000	2.68	-28
30/175M/SS/100/30/5/M	30/175M/SS/100/30/5/M	363	373	0	0	6.4	0	Other	30000	20000	5.34	0
	30/150H/SS/100/30/5/M	258	319	-54	-14	10.7	67	Other	30000	20000	2.68	-50
	30/175M/SS/200/30/5/M	373	186	-187	-50	1.9	-70	Other	30000	20000	7.47	40
	30/150H/SS/200/30/5/M	268	160	-213	-57	4.8	-25	Other	30000	20000	5.87	10
30/175M/SS/50/30/5/M	30/175M/SS/50/30/5/M	358	753	0	0	10.1	0	Other	30000	20000	3.21	0
	30/150H/SS/50/30/5/M	253	644	-109	-14	13.0	29	Other	30000	20000	1.61	-50

Table 41 Reduced Energy Options (Continued)

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) X 10²	ENERGY CHANGE (Kwh/mi/yr) X 10²	ENERGY CHANGE (%)	VI₁₅		AREA TYPE	DENSITY (People/ Sq. Mi.)	VOLUME (ADT)	ACCIDENTS	
						UPGRADE	CHANGE (%)				NEW RATE (ac/mi/yr)	CHANGE (%)
	30/175M/SS/100/30/5/M	363	373	-380	-50	6.4	-37	Other	30000	20000	5.34	66
	30/175M/SS/150/30/5/M	368	251	-502	-67	3.5	-65	Other	30000	20000	6.40	99
	30/150H/SS/100/30/5/M	258	319	-434	-58	10.7	6	Other	30000	20000	2.68	-17
	30/150H/SS/150/30/5/M	263	215	-538	-71	7.3	-28	Other	30000	20000	4.81	50

and six indicate a reduction in energy use while a positive number in the last column represents an increase in accident rate.

It can be seen that in all of the cases, there exist reduced energy options that do not increase accident rate. This normally results from a change to 150 HPS from the existing luminaire (400M or 175M).

A series of examples will now be used to illustrate the results.

Example 1 - Determine most energy efficient upgrades.

Table 42 illustrates the optimum designs under this constraint and their effect on accidents.

Table 42. Optimum Designs

Case #	Optimum Design	Energy Change(%)	Accident Change(%)
1	223	-81	23
2	233	-63	-5
3	288	-81	34
4	258	-81	26
5	268	-81	8
6	223	-81	71
7	233	-63	-25
8	258	-57	-28
9	268	-57	10
10	263	-71	50

Notice that in 3 of the cases, the accident rate is reduced while in the other 5, the accident rate increases between 8% and 71%.

Example 2 - Determine most energy efficient upgrade with no increase in accident rate.

Table 43 illustrates the optimum designs for this constraint and their effect on accidents.

Table 43. Optimum Designs - No Increase in Accident Rate

Case #	Optimum Design	Energy Change%)	Accident Change(%)
1	213	-63	-18
2	233	-63	15
3	278	-63	-11
4	298	-63	0
5	258	-63	-17
6	213	-63	-57
7	233	-63	-25
8	258	-57	-28
9	258	-14	-50
10	258	-58	-17

Example 3 - Determine energy efficient upgrade with maximum decrease in accident rate.

The solution is the same as example 2 except for cases #8 and 10 which become:

Case #	Optimum Design	Energy Change(%)	Accident Change(%)
8	298	-14	-85
10	253	-14	-50

8. SUMMARY

The following can be summarized from the preceding results:

- Total nighttime dry weather accidents are inversely related to visibility as defined by VI15. Higher VI produces fewer accidents. The significance of the result however can only be interpreted when population density and area type are both controlled for.

- Total nighttime dry weather accidents are directly related to both population density and area type. High population densities have a much higher accident rate than other areas. CBD areas have much higher rates than other types of areas. Visibility must be controlled for if the results are to be significant.

- Regression equations have been developed which using area type, population density and visibility (VI15) (and HFC15 for greater significance) as predictors, can predict accident histories for arterial streets.

- Field equipment has been developed which can automatically record target, background, veiling and pavement luminance and which will continuously calculate both contrast and visibility index on-line.

- A target has been developed which incorporates many of the features of the "best" targets used in visibility research.

- A computer program has been developed which can predict illumination, pavement, target and veiling luminances, contrast and visibility for a given combination of road geometry, lighting characteristics and pavement surface type.

- Modern costs have been obtained for the components of urban arterial lighting systems and a methodology developed for computing total system costs.

- An economic analysis has been performed which provides a methodology for selecting the most cost-beneficial lighting systems for urban arterial roads.

- An optimization procedure has been developed which provides a method for selecting optimum lighting designs based on economic, energy, visibility and lighting design constraints.

- Optimum lighting designs for both new and upgraded systems have been developed based on (1) maximum benefit-cost ratios and (2) under the constraints described above.

- All sources (except 175M on wide roadways) can provide cost-beneficial lighting designs for new systems on both 30' (9.1m) and 60' (18.3m) roadways.

- In general, HPS sources are most cost-beneficial, provide better visibility and are more energy efficient than comparable mercury systems. In addition, for lighting systems with Benefit-cost ratios >1, the least expensive systems are all HPS.

- Optimum designs for new systems are split between 400HPS and 150HPS with the latter being slightly favored when energy is the predominant constraint and the former when visibility is the predominant constraint.

- Optimum designs for new systems tend to favor high mounting heights, longer spacings and single sided and staggered arrangements except when visibility is the dominant constraint, at which time lower heights and shorter spacings predominate.

- Optimum designs for upgraded systems will most frequently employ 150HPS luminaires.

- It is possible to design lighting systems with reduced energy which do not adversely affect accident rates. However, if maximum energy reduction is desired, the effect on accident rates is frequently negative.

- A Design Guide has been developed which presents the methodology for the economic and optimization analysis and instructions for use of the VI computer program.

REFERENCES

1. Gallagher, V.P., "A Visibility Metric for Safe Lighting of City
    Streets", Journal of the Illuminating Engineering Society, 5(2),
    January 1976.

2. Gallagher, V.P., Koth, B.W., & Freedman, M. "The Specification of
    Streetlighting Needs", Report No. DOT-TST-72-1, FIRL, June 1975.

3. Janoff, M.S., Freedman, M. & Koth, B., "Fixed Illumination for
    Pedestrian Protection: Phase II", Report No. FHWA RD-72-25, FIRL,
    July 1975.

4. U.S. Department of Commerce, Statistical Abstracts of the U.S., 1973.

5. Tryon, Robert C., "Identification of Social Areas by Cluster Analysis"
    University of California Publications in Psychology, 1955, 8(1),
    1-100.

6. Kay, J.R., F. DeWitt "Cluster Analysis and Multivariate Prediction
    of Community Problems in an Urban Environment". Unpublished doctoral
    dissertation, Temple University, 1973.

7. National Safety Council, "Traffic Safety Memo #113", July 1976.

8. National HIghway Traffic Safety Administration, "Societal Costs of
    Motor Vehicle Accidents", (Unpublished Report; personal communication
    with B. Fargin, NHTSA, December 1976).

9. Cassel, A. and Medville, D., Economic Study of Highway Lighting,
    NCRHP #20, 1966.

10. Janoff, M.S., et. al., "Interaction Between Fixed and Vehicular Illu-
    mination Systems: Phase II", Report No. FHWA-RD-72-73, March 1972.

11. Faucett, R.E., The New Economics of Roadway Lighting, LD&A, January 1973.
    1973.

12. Stemmler, R.E., and Kopka, S.J., "Sunup Reduces Cost of Highway Light-
    ing".

13. Ketvirtis, A. and Rayauskas, S.G., "Interchange Illumination -
    Engineering and Economics", LD&A, October 1973.

14. Smith, R.A. and Goguen, G.P. "Relating Design, Economic Analysis and Energy Conservation Techniques in Highway Lighting", LD&A April 1973.

15. deBoer, J.B., "Modern Light Sources for Highways", Presented at the Annual Conference of the IES, June 1973, Philadelphia, Pa.

16. King, L.E., "Measurement of Directional Reflectance of Pavement Surfaces and Development of Computer Techniques for Calculating Luminance," IERI-87, Final Report, Illuminating Engineering Research Institute, July, 1973 (unpublished draft).

APPENDIX A

LITERATURE REVIEW

The literature reviewed described in this section covered five distinct areas:

(1) Roadway lighting equipment, specifications, and practices
(2) The effects of Roadway Lighting on Traffic Operations
(3) Energy consumption and roadway lighting
(4) Targets for Visibility Studies and Photometric Measurement Parameters
(5) Roadway Lighting vs Crime

A.1 ROADWAY LIGHTING EQUIPMENT, SPECIFICATIONS, AND PRACTICES

A.1.1 Sources

There are 4 basic light sources that are presently being considered for modern arterial lighting systems

> High Pressure Sodium (HPS)
> Low Pressure Sodium (LPS)
> Mercury (M)
> Metal Halide (MH)

All four can be successfully applied on many different roadway geometrics with various mounting heights. Each source also has its own limitations due to manufacturer's specifications, physical size, practical optical control and economics (1).

In general terms, the smaller the source size, the better the light control which can be achieved for a given size luminaire. Phosphor-coated lamps generally produce a greater degree of light in the "glare zone" than clear lamps and will be mentioned briefly.

A summary of the six basic lamp types is presented in Table 44.

Incandescent and Fluorescent lamps have been omitted in this review because they are usually not considered in new lighting configurations due to their very poor economic factors when compared to high intensity discharge lamps and a lack of replacement parts. Even with their poor efficacies, many cities still use the incandescent lamp to light residential streets and fluorescent in tunnels and other limited applications.

Table 44

Lamp Data Comparison*

Source	Watts	Lumen Output	Initial Lumens Per Watt	Rated Average Life Hours
Fluorescent	35-215	2,000 - 16,000	45-80	7,500-16,000
Incandescent	60-860	1,000 - 15,000	15-20	1,500-6,000
Low-Pressure Sodium	35-180	4,650 - 33,200	131-180	15,000-18,000
High-Pressure Sodium	70-1,000	6,400 - 130,000	76-130	18,000-24,000
Mercury	100-1,000	4,00 - 60,000	40-60	16,000-24,000
Metal Halide	175-1,000	10,000 - 90,000	60-125	6,000-15,000

* Data has been approximated

Source: References 1, 2 and 3.

The choice of a lamp for utilization in a roadway lighting system to day generally depends upon the quality of the results obtainable from the systems employing the specific lamp under consideration. These quality characteristics include such factors as glare control, uniformity of illumination, pavement luminance, economics and esthetics. Although color of the light source has been somewhat disregarded when selecting a lighting source, many researchers have found that night traffic vision is not the same under lamps with different spectral distributions and even color temperature with its associated sensation of either warmth or coolness (2).

MERCURY (M)

In the past, mercury lamps have been the most preferred choice for roadway lighting. Advantages of this light source has been its standardization, interchangeability, quality control and long life (16,000-24,000 hrs.). The primary deficiency of mercury lamps is their low luminous efficacy in comparison to HPS or LPS. Table 45 illustrates the most common mercury lamps used for arterial streets.

METAL HALIDE (MH)

The primary use of metal halide lamps has been in high mast lighting of interchanges as well as some high density intersections. The metal halide lamp is very similar in construction to the mercury lamp but contains iodide additives to give a substantial improvement in efficacy and color rendering. Metal halide lamps are commercially available that have efficacies 1.5 to almost 2 times that of mercury lamps. Lamps either have a clear outer bulb or a phosphor coated envelope to further modify the color and generally to lower the color temperature of the lamp (3). Table 46 gives a general description of the specifications of various clear and phosphor coated metal halide lamps.

HIGH-PRESSURE SODIUM (HPS)

High-pressure sodium (HPS) lamps are dimensionally and electrically similar to Mercury lamps but HPS lamps have a much higher luminous efficacy (up to 140 initial lumens per watt) as well as a very high lumen maintenance characteristic (90%). Color is improved over LPS sources because light is emitted in the red, orange, green and blue portions of the spectrum in addition to the yellow. HPS lamps are currently available in sizes from 70 to 1000 watts. Some of the HPS lamp specifications are listed in Table 47.

HPS lamps are relatively compact to take advantage of the radiant light control characteristics of the small light source. Optical systems may use a simple reflector or a more sophisticated reflector/ refractor assembly that can be adjusted to the desired distribution. Overall construction and servicing characteristics are similar to the familiar luminaire types used for mercury vapor.

Table 45

Lamp Data For a Series of Mercury Lamps

	175 W/T[1]	175 W/C[2]	175 W/DX[3]	250 W/T	250 W/C	250 W/DX	400W/T	400 W/C
Overall length in mm	206	206	206	206	206	206	281	281
Luminous flux	7470	7535	8380	11570	11270	11270	20770	22830
Luminous efficacy	42	.43	48	46	45	51	52	57
Rated Life (hrs)	24000+	24000+	24000+	24000+	24000+	24000+	24000+	24000+
Other Bulb Finish	Clear	Phosphor	Phosphor	Phosphor Clear	Phosphor	Phosphor	Phosphor Clear	Phosphor

[1](T) Clear mercury lamp; there is a lack of red radiation and colored objects appear distorted in color rendition.

[2](C) Fluorogermandate phosphor; emits most of its energy in the red region of the spectrum.

[3](DX) Vanadate phosphor; improves efficacy and color rendition and renders skin tones reasonably well.

Source: Reference #3

116.

Table 46

Lamp Data For a Series of Metal Halide Lamps

	175 W/T	175 W/C	400 W/T	400 W/C	1000 W/T	1500 W/T
Overall length in mm.	223	223	287	287	384	384
Luminous flux	12000	12000	32000	32000	95000	1500000
Luminous efficiency	68	68	80	80	95	100
Rated Life (hrs.)	7500	7500	10500	10500	7500	1500
Outer Bulb Finish	Clear	Phosphor	Clear	Phosphor	Clear	Clear

Source: Reference #3

Table 47

Lamp Data of a Series of HPS Lamps

	75W	150W	250W	400W	1000W
Overall length in mm	---	211	257	283	400
Luminous flux	9500	16,000	25,500	50,000	140,000
Luminous efficacy	76	90	102	120	130
Luminous flux at 5000 hours	8400	14,500	24,000	45,000	120,000

Source: Ref. #3

A special type of high-pressure sodium lamp is the HPS retrofit lamp. This lamp can be used to replace the mercury lamp without the necessity of changing the ballast or adding a new starter system. At the present time, the HPS retrofit lamp is available in 360 and 150W versions. Many cities are using the 360 HPS retrofit lamp as an alternative to existing 400W Mercury lamp, consuming less power (15%) for a higher luminous flux, 36,000 lm. The 150W HPS retrofit is also replacing many of the 175W Mercury lamps widely used for residential street lighting. These lamps are not used for completely new installations because of a 25% decrease in lamp efficacy in comparison to standard 400 or 150 watt HPS lamps (4).

LOW PRESSURE SODIUM (LPS)

Unlike all other common light sources, which are panchromatic, LPS produces a monochromatic yellow color hence almost all color discrimination is lost. However, LPS lamps have the highest overall luminous efficiency of all sources - up to 180 lumens per watt.

Like any other type of discharge source, LPS lamps require a ballasting system but unlike other discharge sources which draw a constant power from a ballast, LPS lamps require a ballast to satisfy the increasing wattage supply. A series of various LPS lamps and their data are given in Table 48.

There has been limited use of LPS in this country in comparison to Mercury or HPS sources.

1.2 LUMINAIRES

With the advent to HID sources, many different types of open and enclosed luminaires have been developed to satisfy the requirements for "quality" and "uniformity" in roadway lighting. The luminaire contains

118.

Table 48

Lamp Data of a Series of HPS Lamps

	35W	55W	90W	135W	180W
Overall length in mm	310	425	528	775	1,120
Luminous flux	4,650	7,700	13,000	21,500	33,000
Luminous efficacy	125	138	145	160	180
Luminous flux at 5000 hours	4,450	7,300	12,500	21,500	33,000

Source: Ref. #3

an optical assembly which consists of a reflector or a reflector/ refractor system to gather and organize luminous flux emitted from the lamp and also to achieve a particular light distribution on the road surface. The optimical construction of luminaires with a light distribution suitable for roadway lighting is largely determined by the total luminous flux, luminance, and dimensions of the light source. The light source, therefore, determines the possibility of achieving within practical limits, a distribution permitting large spacing-to-mounting height ratios together with satisfactory uniformity and glare limitation.

The IES stresses the importance of minimizing glare directed against approaching drivers. Luminaires have been classified as cutoff, semi-cutoff or non-cutoff as measures of intensity above the location of maximum candela. A comparison of both the IES and CIE specifications for roadway luminaires are listed in Table 49. Further specifications for glare control recommended by both IES and CIE include higher mounting heights for "long" distributions as compared to the "medium" distribution. In turn, the "medium" distribution is recommended to be mounted at a greater height than the "short" distribution.

The uniformity of illumination is a function of both the spacing-to-mounting height ratio and the luminaire light distribution. The IES has recommended uniformity criteria in terms of a ratio of average to minimum illumination. A uniformity ratio not to exceed 3:1 is recommended and generally accepted, although many state and federal highway authorities are currently prone to accept higher uniformity ratios on arterials and highways (5).

1.3 POLES, MOUNTING HEIGHTS AND ARRANGEMENTS

A variety of poles are presently available for conventional overhead roadway lighting systems including aluminum, concrete, steel and

119.

wood poles. The choice of a pole is usually dependent on the area to be lighted, cost, roadway geometry and the type of distribution.

Table 49

Roadway Luminaire Classification

	IES		CIE	
	90°	80°	90°	80°
Cutoff	25 cd/1000/M	100 cd/100/M	10 cd/1000/M*	30 cd/100/M
Semi-Cutoff	50 cd/1000/M	200 cd/1000/M	50 cd/1000/M*	100 cd/100/M
Non-Cutoff	------------	-------------	1000 cd absolute	------------

+ Maximum Permissible Value of Intensity Emitted

* Up to a maximum of 1000 cd whatever the luminous flux emitted.

As stated in a number of studies, lighting poles represent the major cost element in roadway lighting. Lighting poles also represent a significant collision factor and accidents are usually severe. Estimates from 5 to 35 percent of fixed object accidents have involved lighting poles (6,7).

A number of solutions have been proposed to reduce the number of vehicle-lighting pole collisions including (1) high and low mounting heights (2) greater pole setback and (3) breakaway poles. Of the three solutions, various breakaway poles have been researched and tested in this country and they include aluminum or steel poles with (1) frangible base adapters, (2) progressive shear bases, (3) cast aluminum shear base, (4) notched bolt insert base, and (5) a slip base. Of those mentioned the cast aluminum transformer base, the notched bolt insert base and the slip base appear to produce the least collision damage and are most likely to be most effective in reducing death and injury (8).

Breakaway poles are now used by about 60 percent of state highway departments and many others are planning to use the cast aluminum transformer base, aluminum shoe base, slip base and progressive shear base. Breakaway poles are not used on streets with heavy pedestrian traffic because the lighting poles act as a barrier to protect the pedestrian.

The majority of conventional overhead lighting systems in this country are mounted at heights of 20 to 50 feet (6-16m) depending on the lumen output of the lamp. In recent years, many studies (1,9) have concluded the higher mounting heights give a better uniformity and economy of lighting as well as provide safer and more esthetic lighting.

In general, mounting heights in the 40 to 65 foot (13.1 to 21.3m) range
are the most preferable choice because they reduce the number of lumi-
naires and poles, provide more uniform illumination, improve appearance
and safety and also reduce glare (1,6,10).

The arrangement of roadway lighting is very often limited by the
location of existing poles, block lengths, roadway width, the physical
characteristics of the lamp and the desired amount and distribution of
light cast on the roadway. The four types of pole arrangements are
generally used in this country include: (1) one side, (2) both sides-
staggered, (3) both sides-opposite and (4) median mounted (6). On divi-
ded higheays, the poles are usually located on the right in the direc-
tion of travel and set back usually 2 feet (0.6m) from the curb. Lumi-
naires are suspended over the roadways by either mast arms, brackets
or span wires. Median mounted arrangements are rare on urban arterials
but are utilized when the width is appropriate and rigid median
guardrails and barriers are used. Median mounted installations are some-
times a disadvantage when maintenance is required which may constitute
a safety hazard. In general, staggered arrangements allow for longer
spacing than with one sided, opposite or median mounted because of the
greater uniformity of illumination.

A.2 EFFECTS OF LIGHTING ON TRAFFIC OPERATIONS

A.2.1 Traffic Accidents

Accident statistics during the period of 1967 to 1972 indicate that
the total number of traffic accidents increased by 24% and the total
number of fatal accidents increased by 10%. In 1973, during the oil
shortage, there were approximately 16.5 million accidents accounting for
only a 10% decrease in traffic accidents from 1972 (11).

In 1973, slightly over half of all fatalities occurred at night
with a higher incidence in urban areas than in rural (11).

Accident causation is rarely a simple process and it is difficult
to attribute changes in accident experience to specific countermeasures.
Due to the fact that accidents still occur and at a slightly reduced
level, traffic safety continues to need improvement in all areas (12).

Several general conclusions can be stated concerning the overall
effect of roadway lighting on traffic accidents (13-20).

1. There is no unified agreement among experts about the
   effect of lighting on highway accidents. This lack of
   unanimity pertains not only to the degree of effect,
   but the basic question of whether the effect is negative,
   positive, or neutral.

121.

2. Although results were mixed, *the majority of the articles concluded that improved lighting levels reduced accidents*, especially the more severe. When continuous freeway illumination was under consideration, many researchers found either no impact on accidents or an increase in accident rates attributable to lighting levels and to the introduction of luminaires into the freeway entivonment. However, the severity of accidents was often reduced.

3. The research results indicate proper street lighting has the greatest impact on pedestrian and fatal accidents in urban areas. Reduction in pedestrian fatalities often ranged from 30 to 80 percent.

4. Although definitive cost data were not found, studies consistently indicate that lighting is cost-effective, no matter what accounting method is used to estimate and allocate costs.

The confusion of research results stems from the multiplicity of experimental designs. The reported research varied significantly with regard to location, method of testing, and the definition of accident rate.

Arterial Lighting and Accidents

A number of studies have been conducted which pertain directly to lighting on arterial streets.

An Australian study of 10 sections of main roads (arterials) in Sydney, Australia examined the effect of illumination levels on the ratio of night-to-day accidents. (14) The author studied the lighting on about 130 miles (208km) of main roads with average lighting levels between 1700 and 12,500 average lumens/100 ft. (30.5m) of roadway and the totals of accidents ranging between 192 and 2,200 during a three year period. The results are illustrated in Figure 19 below, and indicate that as illumination level is increased, the ratio of night-day accidents decreases.

Paul Box studied the effect of illumination on accidents on major and collector routes (arterials) in Syracuse. N.Y. (16). Night-day accident ratios were calculated and related to illumination for 329 sections (105 miles (168km)) of urban arterial roadway. The findings were that:

1. Streets with little or no illumination had substantially higher night-day accident ratios and accident cost ratios than the average for all streets in their respective groups. Inadequate lighting, therefore, contributes to accident hazards.

2. The type of street appears to be more of a factor in accident-illumination relations than is the type of abutting land use.

3. Streets with extremely high illumination levels tended to have night-day accident and accident cost ratios that were above the average for each group. It appears possible to "overlight" as well as to "underlight" a given street. However, data on several other important factors (such as streetlight glare, background storefront lighting, or sign lighting) were not evaluated.

4. The apparent minimum (most favorable) night-day ratios of both number of accidents and accident costs were associated with the following levels:

Street Class *	Level (HFC)
1, 2	1.8
3	0.8
4, 5, 6	1.0

5. A substantial benefit-cost ratio would result if lighting on various street sections were upgraded to the values given above.

Relative Accident Experience and Level of Illumination
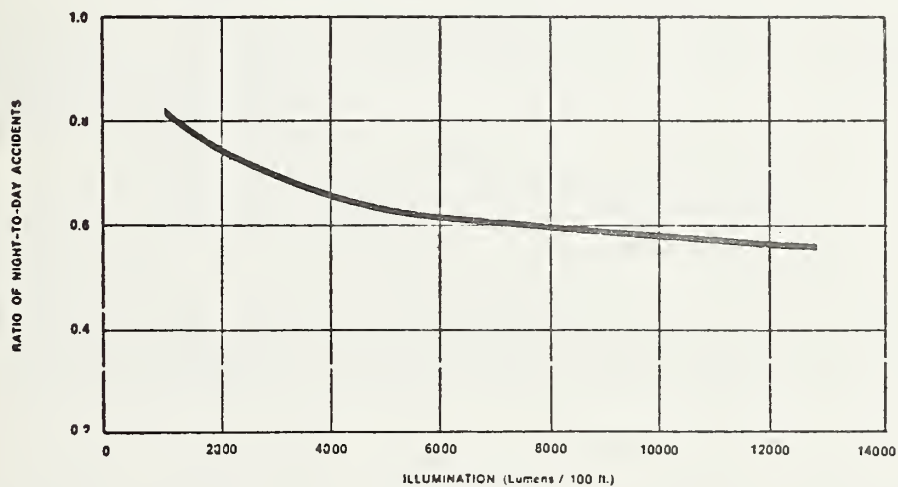

Figure 19

Source: Reference #14.

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* Definition of Class of Street

Major:	Downtown	1	Collector:	Downtown	4
	Intermediate	2		Intermediate	5
	Outlying	3		Outlying	6

Figure 20 illustrates the relationship between illumination level and accident experience found by Box.

Seburn (20) reported on results of the relighting program in Kansas City. This study was restricted to major routes (arterials) and used the ratio of day-night accident in a before-after analysis on 97 miles (155km) of streets. The findings were that relighting of major routes reduced property damage accidents by about 4%, injury accidents by about 18% and fatal accidents about 28%.

In 1966 Paul Box retabulated the Kansas City data based on illumination levels provided in the relighting (17). Table 50 presents the results of this tabulation for fatal and injury accidents.

The trend indicated by these results was that higher illumination levels provided a greater nighttime accident reduction.

Duff(19) reported on a worldwide summary of the effect of lighting on night-accidents. He has compiled results from Britain, Switzerland, Sweden, Australia, and U.S.A. Table 51 presents his findings for "all-purpose urban roads". (His classification which is most similar to "arterial").

In general there was a uniform trend. All results indicated a positive effect of illumination on accidents, although not significantly so in all cases. As in the Kansas City study described above, lighting seems to positively affect fatality and injury accidents, and pedestrian related accidents more so than property damage accidents.

All of the four studies described above have reflected the same results - improved or increased illumination has decreased nighttime accidents. In particular accidents involving pedestrian and accidents involving an injury or a fatality tend to be decreased more by increased illumination. However, the exact relationship between arterial lighting and nighttime safety is still not completely understood.

A.2.2 Other Traffic Operations

No data was found that reflects the effect of lighting on other aspects of traffic operations on arterial streets and only limited data is available that relates lighting to any type of traffic operational data on other types of roadways.

Taragin and Rudy(21), in a study on the Connecticut Turnpike in 1958 and 1959, reported on observations of traffic operations as related to illumination and delineation. The studies were conducted at an on-ramp and an off-ramp.

124.
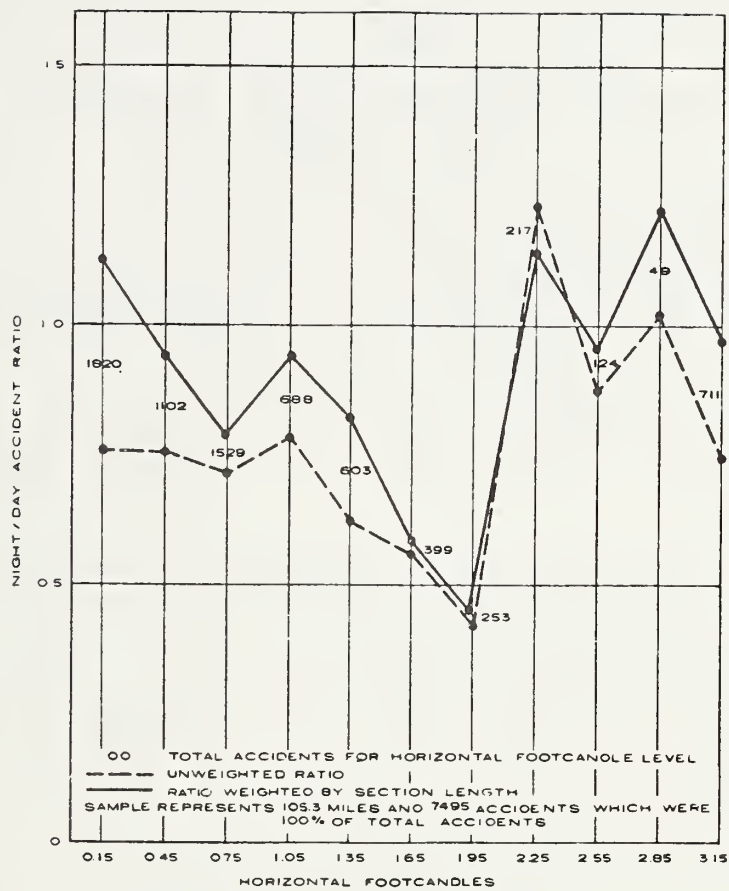
Source: Reference 16

Figure 20

Relation Between Illumination Level and
Accident Experience for all Street Classes.

Table 50

Fatal and Injury Accidents After Major Route
Relighting in Kansas City

Lighting Level (HFC)	Route Miles	Day Accidents		Night Accidents					
		Before	After	Before		After		Change	
				Number	Percent	Number	Percent	Number	Percent
0.2 to 0.39	38.7	80	99	67	46	86	46	+19	+28
0.4 to 0.59	40.8	126	99	173	58	82	45	-91	-52
0.6 to 0.79	7.2	45	23	43	49	23	50	-20	-47
0.8 to 0.89	5.9	31	36	72	70	28	44	-44	-61

Source: Reference 17

125.

Table 51

All Purpose Urban Roads: Effect of Lighting
on Night Accidents

Country	Reduc-tion(%)	Type of Accident	
Britain	45	Pedestrian	64 sites on 2-lane roads
	30	Injury	
Switzerland	36	All injury	12 km.; various sites
Sweden	45	All injury	8 sites; improved lighting from poor to good
Australia	57	Pedestrian Fatalities	34 sites; 93 km.; improved lighting
	21	Non-Pedestrian	
	29	All fatalities	
Japan	38	All acc.; dry roads	13 km.; dual 2 lane with median
	54	All acc.; wet roads	
	44	All acc.; wet and dry roads	
USA	65	Fatal	33 sites in various urban centers
	48	Fatal	533 mi. of arterial streets, 1952-1958
Kansas City	22	All injury	71% of streets re-lighted
	44	Fatal	

This study, made shortly after the opening of the Turnpike, included observations made at low volume rates (313 to 810 vph over all lanes). No consistent changes between day and night conditions by virtue of highway illumination or delineation were shown in this study when considering average speed, placement, and headway. Similarily, in this study no consistent changes in the same three variables were related to changes in illumination, even though higher volumes are observed.

Targain and Rudy reported that the nighttime use of the acceleration lane approached daytime use as illumination increased.

Under NCHRP Project 5-2(1) (22) a study of observations of the traffic stream were made under two intensities of artificial illumination, 0.2fc and 0.6fc (average horizontal) and under daylight conditions, together with an analyses of the accident rate under day and night conditions over a 5 year period. Study sites included tangent, curve, on-ramp and off-ramp and control sites for the first two types of sites.

The principal results of the observations were as follows:

1. The distribution of passenger vehicles and commercial vehicles by lanes was unrelated to the lighting conditions — similar volume levels resulting in similar lane usage — under either level of illumination at all observation sites. Flow rates in the daytime observations were greater than at night, but percentage of lane use did not change, except for a decrease in the percentage of trucks.

2. In general, when a change in placement did occur vehicles tended to travel closer to the right-hand edge of a lane when nighttime illumination increased. A change in mean placement (about 0.5 ft) was observed at the tangent test site for all lanes, for both passenger and commercial vehicles, with similar but lesser shifts (about 0.3 ft) in mean placement observed at the tangent control site. At the other three sites (curve, on-ramp, and off-ramp) there was no uniform change in mean placement, changes greater than 0.2 ft occurring in only one or two lanes at any site. Daytime placements were within 0.2 ft of one or the other sets of nighttime placements, and did not favor either level of illumination.

3. There was no pattern of change in variation in placement when related to a change in illumination level. Daytime variances in placement were not related to one particular level of nighttime level of illumination.

4. Statistically significant changes in mean velocity were obtained in all but one (of the eight possible) lanes for passenger vehicles at the curve and off-ramp when the illumination intensity was changed. Changes in velocity at the tangent and on-ramp sites were not as great as at the other two sites, but all mean velocity changes were less than 2 mph, even when statistically significant. Those changes that did take place indicate a tendency for mean speed to decrease with an increase in lighting intensity. Similar changes were found for mean velocities of commercial vehicles, but were not statistically significant, because of smaller sample sizes. Daytime velocities were less

127.

than nighttime velocities at some locations and greater at others, but the differences rarely exceed 2.0 mph. Daytime velocities showed no tendency to be more identifiable with one nighttime level to the exclusion of the other.

5. The influence of lighting change on variation of speeds were mixed. Increases and decreases in standard deviation were noted when the intensity of illumination was increased. Changes in variation of speeds were also observed at the control sites where no change in lighting took place. There does not appear to be a relationship between variation in speed and changes in lighting. Daytime variances were less than nighttime variances but not related particularly to variances observed at one level or the other.

    Analysis of headways within lanes and between lanes indicated no relationship between intensity of illumination and deviation of observed headways from the theoretical headways determined by a negative exponential distribution. Daytime headways were observed to underestimate low headways (0 to 0.5 sec) in amounts similar to nighttime observations.

7. The influence of headways was further analyzed by separating out vehicles which had headways both in front and behind of more than 6.0 sec. Two other categories include those vehicles with one headway (either before or after) greater than 6.0 sec. The final category included vehicles with neither leading or trailing headway greater than 6.0 sec. The velocities of vehicles with headways both fore and aft greater than 6.0 sec are significantly different from velocities of vehicles in other headway categories. Headway categories and placements are unrelated. The relationship between headways and velocities is independent of illumination, day or night.

8. An examination of clustering of vehicles, by vehicle type, showed that the patterns were different at the various test sites. At the two ramp sites (on-ramp and off-ramp) commercial vehicles were observed in clusters of two or more successive commercial vehicles more often than expected from the number of commercial vehicles in the stream. There was no evidence of clustering relating to changes in illumination or to daytime.

9. Observations of the percentage of merging vehicles, the gaps accepted by the merging vehicles, and the point of merge into the through lane at the on-ramp site showed no significant difference when related to the change in illumination or to daytime observation.

The results of this study did not show any substantial differences from the conclusions of Taragin and Rudy discussed above. In general both studies revealed no differences in operating characteristics resulting from freeway illumination.

A.3 ENERGY CONSUMPTION AND ROADWAY LIGHTING

A.3.1 Discussion

On initial observation, roadway lighting appears to be one of the prime users of large amounts of electricity but upon further research, roadway lighting probably accounts for less than 1 percent of total annual electrical power consumption (23,24,25). It can also be noted that most of the roadway lighting energy usage is consumed during off-peak hours and the availability of energy for arterial and residential street lighting may not be a constraint.

On January 8, 1974, the Federal Register issued a proposal that the energy for highway lighting be reduced by 50 percent. This does not imply that half the roadway lighting systems should be turned off or removed. Energy consumption by roadway lighting systems can easily be reduced by 50 percent if the design follows IES guidelines concerning lamp choice, luminaire performance, hours of usage, efficiency and maintenance.

IES has also responded to an appeal from the Energy Advisory Committee to work toward a system of performance oriented lighting level recommendations for specific tasks reflecting the variables of speed and accuracy in performing that task. IES stated "that illumination levels be based on the principle of visibility levels and their effect on visual performance, including corrections for field factors such as age, significance of errors and visual components" (3,26). So, in determining the desirable pavement illumination and luminance to a specific task, it is necessary to look at the corresponding roadway geometries and traffic conditions. Similarly, the selection of efficient lamps and luminaires that have the appropriate light distribution for a particular roadway geometry will show a great effect on energy utilization.

CIE has indicated that the cost of energy saved by reducing road lighting can not even begin to cover the resulting accident costs. Even though roadway lighting uses a very small part of the total electrical consumption, it is necessary that all efforts be made to avoid wasting energy and to maximize the use of available energy (27).

A.3.2 Energy Availability and Utilization

The uneven demand for electrical power causes drastic increases in energy cost. In most of the U.S. there are daily peaks during the morning and late afternoon where inefficient generating plants are usually operating.

In contrast, during slack periods the most efficient generating plants are operating which has influenced some utility companies to start pilot programs encouraging off-peak electrical use when production costs are low. Energy costs have risen but peak use has remained relatively constant.

Roadway lighting has a distinct advantage in that it contributes to load equalization because of the small consumption and the time in which it is used. The overall beneficial effect would be an attenuation of the fixed charges and the reduction in costs per kilowatt hour.

A report by LEAA (23) has estimated that the total power consumption for all the nation's street and highway lighting systems is approximately 0.7 percent of the total electricity generated, while the Edison Electric Institute has found the figure to be 0.8%.* It was also found in the study that electrical consumption for concentrated urban areas was somewhat higher. Estimates by the Federal Power Commission* revealed that the average street light uses only about .22 gallons of oil per day.

Karl Southward (24) expresses strong disagreement with some of the methods and priorities that energy conservation programs have had on lighting. He points out that a 50% uniform, nationwide reduction in all lighting usage (both inside and outside) will cause the U.S. "to utilize more consumer usable oil and gas as well as cost the nation an additional .03%." He states that all lighting uses about 5% of the total electrical energy while roadway lighting accounts for only about 1% of the total.

In contrast, Thomas Lemons (25) advocates a moratorium on outdoor lighting and the "light-up-the-night philosophy". He seriously questions whether roadway lighting can accomplish the reduction of street crime as the cost of energy and the need to conserve increases. Lemons recognizes the fact that all lighting electrical energy usage is less than 5 percent but bases his arguments against excessive outdoor lighting on the premise that "a penny saved is a penny earned". Lemons concludes by stating that established guidelines for lighting are necessary for lighting to follow its intended purposes of visibility, safety and security.

Chamberlain (28) explains that in the process of trying to conserve energy by haphazardly turning off street lights, many cities will eventually pay further costs in higher crime rates, reduced business activity and more frequent and severe traffic accidents. He suggests that cities should turn to more efficient light sources as a result will receive much more light output at a savings in energy and dollars.

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* Information supplied by FHWA.

A.3.3 Energy Conservation in Lighting Systems

LIGHT SOURCE SELECTION

Since roadway lighting lamps vary in luminous efficacy anywhere from 15 lumens per watt to 180 lumens per watt, it is of primary importance to choose efficient light sources that are compatible with the road geometry. The choice can also relate to color quality, source controlability, lamp life hours, and also the ease of maintenance.

The use of incandescent sources for roadway lighting seems absurb when one considers the number of other discharge sources that provide greater luminous efficiency. The source with the highest efficiency, the low-pressure sodium lamp, is generally not used as widely as others. Color rendition of the LPS lamp as well as lamp size and shape has limited its application in U.S. roadway lighting. Many researchers still can not agree on the importance of color for good visibility. Where amenity considerations have priority, the use of the HPS or mercury sources are recommended. The varied wattages of these sources make them suitable for a broad range of roadway application requirements.

Table 52 illustrates some recent examples of energy savings resulting from changes in lighting sources.

MAINTENANCE

The maintenance of outdoor lighting installations is an important factor in energy consumption since urban industralized environments cause luminaire dirt accumulation to reduce performance (25). Some other factors to consider in the maintenance of adequate illumination are the depreciation in lumen output due to aging, filament deterioration and lamp blackening and also lamp outages due to circuit failure, accidential breakage and vandalism

The calculation of light loss factor should be of prime importance in the initial lighting design as well as in determining maintenance programs. Factors such as lamp lumen depreciation, luminaire dirt depreciation, burnouts allowed, voltage and outside temperature should be considered in light loss. The prediction and the insistence of frequent group lamp replacement and luminaire cleaning will give the best light loss factor as well as reduce required energy (29).

CONTROL PLANNING

Switching, dimming, multilevel ballasting as well as photocells should seriously be considered as another method of reducing energy consumption. Two lighting control devices that are being used to regulate the time street lights remain on are the time-switch and the photocell. By the careful choice of an array of certain lights to be switched off or varied during low traffic density periods, "energy savings of 25%

131.

Table 52

Lighting Changes and Energy Savings

Location	Change	Energy Savings
Philadelphia, Pa.[1]	20,000 lamps from 400 watt M to 360 watt HPS	10%
	56,000 lamps from 175 watt M to 150 watt HPS	14%
	100 lamps from 1000 watt M to 400 watt HPS	50%
		Total Annual Savings of 18,000,000 kwh (Total Savings of $500,000 per year)*
Chicago[2]	175 & 250 watt M to 150 watt HPS	14-40%
	400 Watt M to 310 watt HPS	22.5%
Dothan, Alabama[2]	72 lamps from 400 watt M to 360 watt HPS	10%
Salem, Oregon[2]	250 lamps from 1000 watt M to 400 watt HPS	60%
N.Y.C.[2]	M to HPS	1,000,000 gallons of oil per year

(1) Personal Communication with C. Oerkvitz, Phila. Street Lighting Engineer

(2) Chamberlain - Reference 28

* Electricity Savings: $850,000
  Increased Maintenance: $350,000

  TOTAL SAVINGS $500,000

132.

could be made" (30). Time switches may not be very economical if only a small number of lights are affected. Photocells on the other hand are located on top of each luminaire and operate the lamp only when illumination levels are low and turns the lamp off at dawn or at a predetermined time before dawn. Chamberlain states that if cities would use newer "time photocells", a city can reduce energy drain by up to 50%" (28).

A.3.4 Summary

The consensus of opinion in the papers reviewed that relate energy consumption to roadway lighting is that roadway lighting, although it appears to be a major user of electricity, in effect accounts for probably less than 1% of the total annual electrical consumption.

Even with this 1% figure, savings in energy use ranging from 10% up to over 60% can be achieved by replacing older mercury lamps with the more modern HPS sources. Far greater savings can be realized by upgrading both incandescent and fluorescent sources to either mercury vapor or, more economically, HPS. Adequate maintenance of these sources could further increase the energy savings, since lack of maintenance can cause up to a 50% reduction in performance while additional savings can result from the use of time switches and photocells, multilevel ballasts, dimming and switching devices.

A.4 TARGETS FOR VISIBILITY STUDIES AND PHOTOMETRIC MEASUREMENT PARAMETERS

Although procedures to assess roadway visibility are diverse, all involve some consideration of the visibility of targets placed on the roadway. Several visibility meters have been constructed since 1920 which enable the visual threshold of a target to be determined through either luminance reduction or luminance contrast reduction or both, and thus quantify target visibility. Blackwell (31) has developed one such visibility meter that has found international usage. His research concerning roadway illumination has utilized a scale model section of roadway complete with appropriately dimensioned luminaires. Several researchers have developed visiibility assessment methods for the evaluation of vehicular headlighting. These methods generally involve the determination of target detection distances under various headlighting configurations, although Farber (32) has developed an empirical nightvision model for Ford Motor Company whick includes dynamic glare effects. Of the Europeans involved in visibility assessment research, Schrduder has extensively studied the visual perceptual difficulties encountered by motorists during tunnel transitions, and Adrian has specified photometric determinants of disability glare. Research conducted by Phillips Gloeilampenfabrik is intended to actively pursue lighting market technologies through mobile pavement luminance measurement systems.

The quantification methods employed by visibility researchers all utilize different targets and luminance measurement parameters. Although

133.

the selection of a particular target configuration, size, reflectivity, and similarity to actual roadway objects is somewhat arbitrary, very little discussion of the method of selection is generally offered. Characteristics of targets used in visibility assessment research are presented in Table 53. Photometric measuring parameters employed in conjunction with these targets are presented in Table 54. These tables include information about past FIRL visibility assessment research.

A.4.1 International Visibility Assessment Techniques

Schreuder (33,34) and Adrian (35) utilize relatively small 3.5 to 7.9 inches (9 to 20 cm) principal dimension geometrically shaped two-dimensional objects as targets in their visibility quantification procedures. The targets possess reflectivities yielding a luminance contrast with the background roadway pavement in the range of .20 to .35, and are intended to simulate roadway obstacles such as broken vehicle parts, rocks, etc., which must be avoided by motorists. Schreuder has proposed (34) that such a target be recognized as an international standard object for visibility research. Besides representing the object-avoidance driving task, Schreuder believes that his recommended target configuration corresponds to the visual task of motorists in detecting and recognizing the future path of pedestrians.

In research attempting to determine the luminance levels needed at long tunnel entrances to relieve the black-hole and black-out effects experienced by approaching motorists, Narisada (36) employed a 5.9 inch, (15cm) square target with reflectance coefficient of 25%. In his later examination of the "dark frame" effect noted at short tunnels in which the bright exit is visible on the approach roadway, Narisada (37) chose a 7.9 inch (20 cm) square object with 30% reflectance. This size was selected to represent "the smallest obstacle still dangerous to traffic", i.e., an object which must be avoided rather than driver over. Since visibility conditions in short tunnels involve silhouette viewing, the greater the target reflectance coefficient the lower the resulting luminance contrast (given constant roadway luminance) and therefore the greater conservatism in the research approach utilizing the 30% reflectant target. Narisada claims that most roadway obstacles to be avoided by motorists have low reflectance and that 30% represents a suggested maximum value of reflectance for such objects.

A.4.2 Visibility Meters

Visibility meters are defined as devices used for psychophysical measurements of task visibility under different illuminance and luminance conditions. Visibility meters reduce the visual task to a threshold level by manipulating the target size, luminance, or luminance contrast through known degrees of attenuation. The visual difficulty of a practical task can therefore be determined relative to some standard. Fince and Palmer (38) have extensively reviewed the principles and functional efficacy of seven visibility meters. Their conclusions,

Table 53

Characteristics of Targets used in Visibility Assessment Research

Researcher	Source Ref.	Dimension- ality	Shape/Con- figuration	Nominal Size	Viewing Size	Reflectance
Gallagher	48	3	Truncated traffic cone	18 in H (46 cm)	25' H	6% & 29%
Janoff	15	3	Truncated traffic cone	18 in H (46 cm)	34' H	8%
Schreuder	33,34	2	Square	7.9 in^2 (20 cm)	No data	20%*
Adrian	35	2	Square	3.5 in^2 (9 cm)	8-10'	35%*
Finch	38,40	2	Circular Disc	18 in DIA (46 cm)	17' to 69'	10%
		2	Pedestrian	5ft H by 1ft (1.5m by .3m)	34' to 4 deg	10%
		3	Octagonal section	18 in DIA (46 cm)	17' to 69'	10%
Blackwell	44	2	Pedestrian	6ft H (1.8m)	1.7 deg H	43%, 26%, 7%
	44,46	2	Rectangle	32 in H (81cm) by 12 in (31cm)	46' H by 17' W	73%, 15%, 32%, 4%
Farber	32	2	Pedestrian	2.77ft. (84cm) DIA	24'	17%

135.

Table 53. (Cont.)

Characteristics of Targets used in Visibility Assessment Research (cont.)

Researcher	Source Ref.	Dimension-ality	Shape/Con-figuration	Nominal Size	Viewing Size	Reflectance
Mortimer	47	2	Pedestrian	6ft H (1.8m) by 1ft (.3m)	N/A	14% & 22%
		2	"Up/Down"	6 in (15cm) H or 24 in (61cm)	N/A	14% & 22%
		2	Vertical Strip	Not given	N/A	18% to 100%
Narisada	36	2	Square	5.9 in^2 (15cm^2)	5.2' H	25%
	37	2	Square	(7.9 in^2) (20 cm^2)	6.9' H	30%

* Specified in terms of luminance contrast with pavement background. N/A = Not Appropriate.

136.

Table 54

Photometric Measuring Parameters Used in Conjunction with Targets Listed in Table 8.

Researcher	Source Ref.	Viewing Distance	L_T Field Size	L_B Field Size	Viewing Angle Gel. Horizontal	Observer Height	No. Measurements Made [1]
Gallagher	48	200ft. (61.0m)	6'	30'	1 deg.	43 in (1.1m)	2
Janoff	15	150ft (45.7m)	15'	1 deg.	1.4 deg.	43 in (1.1m)	2
Adrian	35	282ft (85.9m)	N/A	2 deg.	1 deg.	59 in (1.5m)	1
Finch	38,40	75-500ft. (23-152m)	2 deg. [2]	11 deg. [3]	No data	No data	1
Blackwell	44	200ft. (61.0m)	1.5 deg. [2]	3 deg. [2]	1 deg.	48 in (1.2m)	1
		200ft. (61.0m)	2'	2'	Variable	48 in (1.2m)	20
	46	200ft. (61.0m)	2'	2'	Variable	53 in (1.3m)	15
Farber	32	400ft. (121.9m) 70ft. (21.3m)	4'	10' 2 deg. [4]	No data	No data	3

N/A = Not Appropriate

1. *For simple contrast computation.*
2. *Using visibility meter: only one measurement made.*
3. *Area of total viewing field of visibility meter.*
4. *Used for adaptational level B_f only.*

137.

which coincide with recommendations of the C.I.E.(39), indicate that the visibility meters operating through the reduction of target contrast yield the best results. In an evaluation of the Finch Visibility meter (38,40), a discussion of the appropriateness of targets for visibility assessment has been offered. Studied were a small two-dimensional circular disc and a small three-dimensional octagonal section (both having a diameter of 18 in or 46cm) as well as a tall (5 ft., 1.5m) thin (1 ft., 0.3m) target simulating a pedestrian. Diffuse reflectance coefficients of all targets was .10. Target visibility was measured under illumination from a relatively uniform (U.R. = 1.3:1) and non-uniform (U.R. = 19:1) lighting configuration. They conclude that

in extremes of pavement brightness variation, small targets are much more easily lost in the pattern than larger targets. This is particularly true with two dimensional targets...Some data...for tall thin targets simulating pedestrians...indicate that for practically all positions on the roadway the target is above the contrast threshold at some point on the target and therefore extremes of visibility do not occur...Information concerning the variation in visibility over the test area of the roadway is not as evident when such targets are used. Therefore it is believed that...smaller targets in the order of 12 to 18 inches in principal dimensions are more suitable for appraisal purposes than targets simulating pedestrians.(38)

It is apparent from this discussion that three-dimensional targets are required to demonstrate the visibliity effects of directional fixed lighting leading to non-uniformities in pavement luminance.

Blackwell has also developed a visibility meter, termed the Visual Task Evaluator(31), which quantifies the Visibility Level (VL) of a target at visual threshold through the principle of luminance contrast reduction Blackwell's VTE and associated methodology have been incorporated into the C.I.E. recommended method for evaluating roadway lighting(39,41), and have been lauded as an attempt to standardize visibility assessment techniques to facilitate comparisons(42). The VTE was developed utilizing a 1:15 scale model of an eight-lane roadway section (43). Early Blackwell visibility research with the simulated roadway (described in 44) utilized a manikin target simulating a 6 ft. (1.8m) tall male pedestrian, possessing a diffuse reflectance of either .434, .260, or .074. Targets were placed every 20 ft. (6.1m) within the luminaire spacing cycle under study. Observer height for the VTE was 48 in (1.2m); observation distance was 200 ft. (61.0m). For each target location in each of the lanes of the simulated roadway, effective threshold target contract was determined using the VTE. Results in VLeff were averaged across all target locations: Blackwell presented these averages as well as the average deviation to convey the variable distribution of VLeff across the roadway. Results indicated that

at least to some extent, luminance non-uniformity can be
a boon (to visibility) in that it provides such a variety
of values of roadway luminance that some part of an object
is sure to be seen because an appreciable local contrast
exists.(44)

Blackwell terms this consequence of pavement luminance non-uniformities
the "anti-camouflage effect", and suggests that it is a consequence of
target reflectance, i.e., the particular superimposition of target lumi-
nance upon the background pavement luminance. These visibility effects
noted by Blackwell are similar to the Finch(38,40) observations regard-
ing the interaction of target configuration and pavement luminance uni-
formity.

To study this phenomenon further, Blackwell(44) constructed a two-
dimensional rectangular target 32 in. (.8m) high by 12 in. (.3m) wide
with variable reflectances of .726, .508, .317, and .044. The pave-
ment against which a target of this height is seen extends roughly 300
ft. (91.0m) beyond the target, a distance comprising at least one lumi-
naire spacing cycle. This roadway area also corresponds to the C.I.E.
trapezoid for measuring "mean" pavement luminance(45). Blackwell noted
that several target locations yielded low VIeff in the shorter luminaire
spacings, indicating that a "camouflage" effect was occurring because
of the high degree of pavement luminance uniformity. The average devia-
tion of VLeff also decreased with luminaire spacing.

In order to properly evaluate the camouflage and anti-camouflage
effects, Blackwell made discrete target luminance and immediate back-
ground luminance measurements so that physical luminance contrast could
be compared with the threshold contrasts determined with the VTE. Uti-
lizing the rectangle, five target and fifteen background luminance
measurements were made with a small (2 arc-minute aperture) measuring
field. Measuring points are depicted in Figure 21. Other photometric
parameters remained the same. Physical contrast was computed for each
background measurement and all contrast values were subjected to a cor-
relation analysis relative to threshold contrast values of the same
target. Results of the correlation analysis indicated the highest degree
of association between VTE values and average physical contrast values
when the bottom five background measuring points were excluded, i.e.,
when the target shadow upon the pavement was not included in the physi-
cal contrast average. Blackwell suggests(46)that visibility assessment
research utilize background measurements only on the left and right
sides of his rectangular target. Also recommended is the reliance upon
physical luminance contrast c rather than threshold contrast determina-
tions using the VTE.

A.4.3 Vehicular Headlighting Evaluation Studies

Studies quantifying visibility effects of vehicular headlighting
systems generally are of limited utility relative to basic visibliity
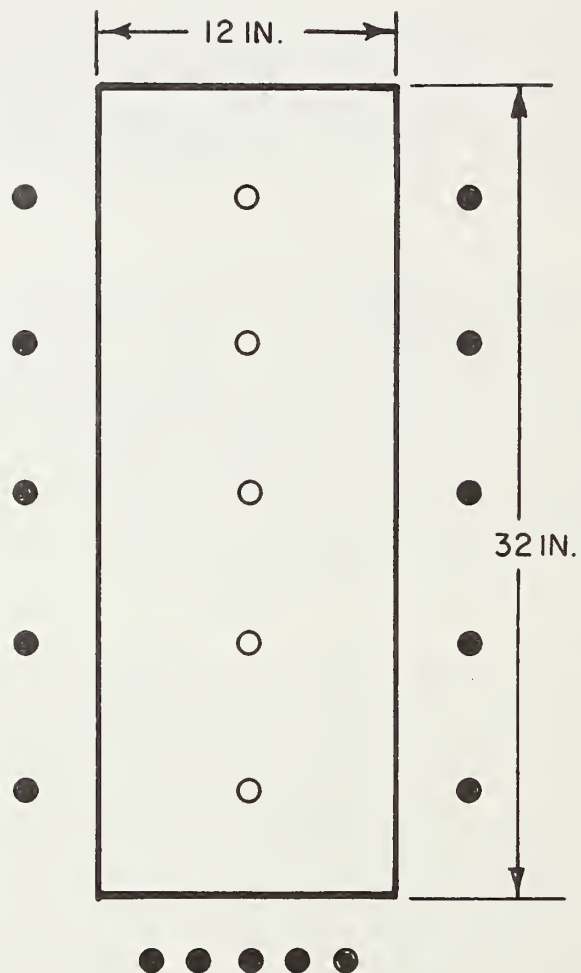
O TARGET LUMINANCE MEASUREMENT POINTS
● BACKGROUND LUMINANCE MEASUREMENT POINTS

Figure 21. Schematic of Blackwell Target with Luminance
Measurement Points.

research, because a static detection task is employed. This task requires driver subjects to subjectively determine the distance from a target on or next to the travelling lane at which point the target becomes visible. Results of these studies are in the form of detection distances or visibility distances.

An empirical night-vision model for evaluating headlight systems relying upon photometric measurements has been developed by Farber and Bhise(32). They utilize a large vertical two-dimensional target appropriately shaped like a pedestrian. The area of the target was equivalent to the area of a circle 2.77 ft. (.84m) in diameter. Target luminance measurements were taken in a very small (r-arc-minutes) area within the target; background measurements comprise a rather large area around the target (see Figure 22). During the headlighted vehicle approach situation, the roadway exhibits a brightness gradient (levels Bj in Figure 22) with the highest intensity levels in the near foreground (Bf), roughly 50 to 100 ft. (15 to 30m) from the observer. The Ford luminance contrast formula reflects the change in motorist adaptational state caused by Bf appreciably greater than Bi (background luminance). Farber & Bhise visibility data indicate useful application of the model to headlighting system design and evaluation, although they do not present visibility data which might be useful in determining optimum targets for our research.

In another vehicular headlighting evaluation study, Mortimer(47) discussed the use of several target configuration and visibility-related consequences of their usage. The primary selection of targets included (1) several tall and thin targets (no dimensions given), (2) an "up/down" target, resulting in the target face being either 24 in. (61cm) or 6 in. (15cm) above the pavement, (3) a "choice position" target which had markings at various orientations, and (4) a plywood pedestrian simulation 16 in. (40cm) wide and 72 in. (1.8m) high with a reflectance of .14 or .22. Detection distances for these single-plane targets under illumination from vehicular high- or low-beam headlamps were determined for several subjects. Results indicated undesirable characteristics of all except the "choice" targets. Under low-beam headlamp illumination, the vertical target detection distances did not vary with target reflectance or target size (see Figure 23), although under illumination from high-beam headlamps, detection distances increased with both target reflectance and height. Mortimer suggests that the vertical targets tended to cast shadows upon the surrounding roadway and were detected on that basis alone. Both up/down and pedestrian targets were detected in silhouette viewing, which was considered undesirable in this study because of the requirement of direct viewing. The up/down target detection distance was greater with the face down, i.e., close to the pavement, rather than with the face up. Presumably this result is also due to silhouette viewing against the illuminated pavement background. Whereas Mortimer dismissed the use of these targets because a direct-viewing target with internal contrast and detail was desired, their use

$$C = \frac{B_T - B_i}{B_f}$$
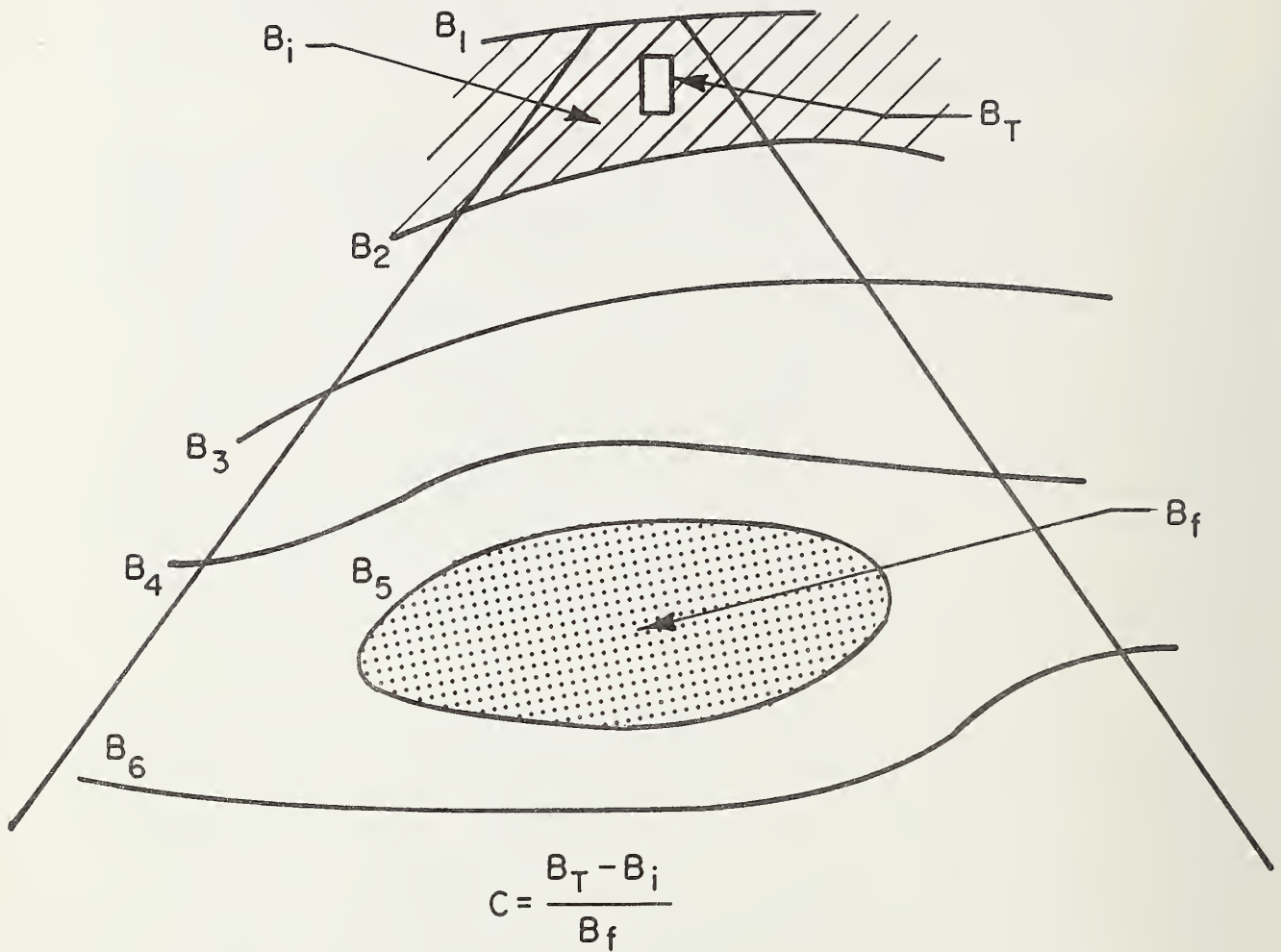
B_i = Background Luminance Field

B_T = Target Luminance Field

B_f = Foreground Luminance Field

B_j = Levels of Longitudinal Roadway Brightness Gradient

Figure 22. Schematic of Farber & Bhise Photometric Measurement Parameters.

142.

for our research is not indicated primarily because they are single-plane targets and therefore are not sufficiently sensitive to directional characteristics of fixed lighting.
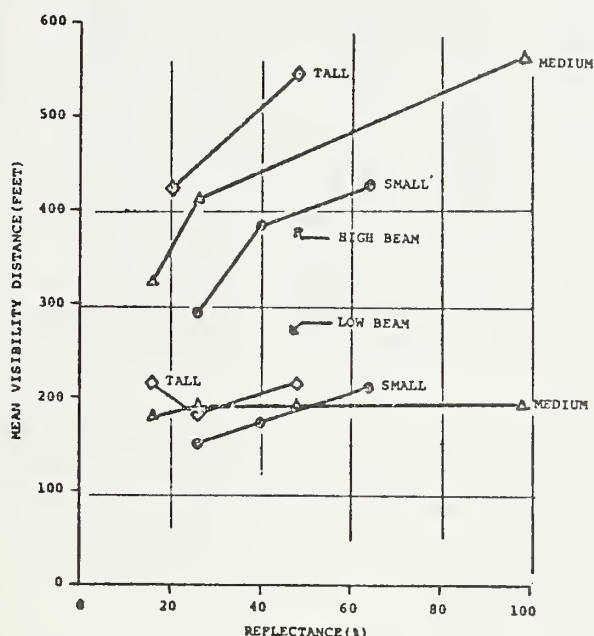
Figure 23. Mean Visibility Distances of Vertical
Targets Used by Mortimer

A.4.4 Optimum Target Specifications

Past visibility assessment research at FIRL(15,48) has employed a three-dimensional target with satisfactory results. A standard rubber traffic cone truncated to a hgieht of 18 in. (46cm) has been used with either a matte-finish grey (reflectance = 6%) or white paint (reflectance = 29%), or a velour paper covering (reflectance = 8%). The use of this target has provided a simple shape without internal contrast as well as safety and crash-survival properties.

The primary criterion in determining the optimum target configuration for the present research was that it should be sensitive to the local longitudinal and lateral illumination gradients at a given roadway location so that the resultant target and background luminances can be quantified in VI and DVI. To exhibit the visibility effects of directional fixed street lighting, which are apparent as degrees of pavement luminance uniformity(38,40,44), the target must be relatively small (38,40,49), low to the ground so that target visibility is a result of

143.

local background luminance exclusively(47), and have a relatively small surface area within the plane normal to the direction of viewing. These criteria indicate the appropriateness of multi-faceted or spherical, three-dimensional target. To avoid the confounding of target contrast with shadow effects(38,46), a target lacking both lower contours (i.e., below the target's horizontal equator) and internal contrast is desired. This suggests a hemispherical shape with a lower cylindrical "skirt", as depicted in Figures 5 and 6 of Section 3. Minimum diameter will be 16 in. (15cm), which is the practical lower limit size for roadway obstacles(36) and the target height recommended by the ITE(49) and the AASHTO(50) for use in determining minimum sight distance on vertical roadway curvatures for safe stopping. An examination of the relationship between degrees of vertical roadway profile crests for minimum stopping distance and target height by the AASHTO revealed that the required length for vertical curves diminished rapidly as target height was increased from 0 in. (0cm) (the ideal, signifying visibility of the actual roadway surface) to 6 in. (15cm). Target heights greater than 6 in. (15cm) yielded little improvement in sight distance, identifying the 6 in. (15cm) height as the "approximate point of diminishing returns" while still reflecting concern for a range of objects such as "small animals, merchandise dropped from a truck, or rocks rolled from a side cut" to be seen by motorists to avoid collison(21).

A.5 ROADWAY LIGHTING VS CRIME

A.5.1 Introduction

Ideally it would be beneficial to determine crime rates in relation to level of illumination. However no study to date has revealed such relationships. There have been a number of studies that have indicated a before vs after average illumination level and corresponding crime frequencies(51,52,53,54) but the dissimilar areas (Kansas City, Milwaukee, Miami, Portland) with their differences in crime, population, densities, deterioration, median income etc. prohibit direct comparison of data. No individual area has stratified crime reductions vs level of illumination. The illumination levels for these four areas range from less than .1 hfc in the before case to greater than 4 hfc in the after conditions.

A.5.2 Summary of Upgrading Programs

Table 55 presents information on (i) lighting data, (ii) research design, and (iii) crime changes for a number of cities, excluding Kansas City.

The first group of columns, headed "Lighting Data," shows the date of lighting change, the type of new light used and the number of these lights, the dollar cost of installation and maintenance, the size of the relit area, and some description of the characteristics of the area.

144.

Table 55.

Reported Experience with Street Lighting and Crime (p.1)

(1) Lighting Data

City	Change Date	Lights (type,number)	Cost	Area Size	Area Type
Milwaukee	1972	sodium		3.5 sq. miles	Private and multi unit residential commercial. Elderly
Miami (1)	1971	sodium		1.8 sq. miles	Central business district. Includes apartment houses
(2)	1971	sodium 350			Garment district. Small industries
Tampa	1970-71	sodium 445			Police designated (high crime)
Owensboro, Kentucky (Pop 55,000)	1968-1970	mercury 5000	$415,00	Citywide	Streets; major, collector and residential (emphasized)
Washington, D.C. (1)	1970(late)	sodium 3800	$1,000,000	113 blocks	Four high-crime residential block-groups
(2)	1970 April	sodium			2(a)- single neighborhood, NW DC
					2(b)- RFK stadium parking lot
Portland, Oregon	Dec.1972 - Jan.1973 May 1973 - June 1973	175W.HPM-70001umen 172/158 lights	51,829	315 blocks	North and Northeast Portland High crime areas (police designated)

Reported experience with Street Lighting and Crime (p.2)

(ii) Research Design   (iii) Crime Change Data

City	Test Period	Baseline Period	Control Area	(Total) All Crimes(%)	Murder (%)	Rape (%)	Robbery (%)	Assault (%)	Burglary (%)	Larceny (%)	Auto (%)	Other (%)
Milwaukee	1-7/72 vs 1-7/73	71 - 72	adjacent streets	Base/Test Relit:-23/-15 Control:-08/+18								
Miami(1)	1971 vs 1972		citywide	test +01 control +01	-.11 -.32	-33 -49	-39 -13	-24 -14	+6 -2	-3 +15	-7 -12	
(2)	Oct-Nov'70 vs Oct-Nov'71	1969 - 1970		base/test: (felonies)+15 (total)-49								
Tampa	1-6/70 vs 1-6/71		Other Bay Area cities	test: (person crimes) -56 control: "rise"								
Owensboro, Ky. (pop 15,000)	1967 vs. 1969		nationwide	test -34 control +11			-50		-27	-31	-39	
Washington D.C. (1)	1970 vs.1972	1969 - 1970		base/test: -16/-54			-14/-65		-26/-44		-8/-56	vandalism -19/-22
(2)a	4-7/70		citywide	test: control:			-25 -8.3		-63 -6			vandalism declined
(2)b												
Port-land	Jan-Nov 72 vs Jan-Nov 73 / June-Nov 72 vs June-Nov 73	71/72	Adjacent areas *Control areas				* *	* *	* *			

* - No Significant Changes

146.

Reported Experience with Street Lighting and Crime (p.3)

(1)Lighting Data

City		Change Date	Lights (type,number)	Cost	Area Size	Area Type
Cleveland	(1)	1966-73	mercury 58,000	$6,500,000	1,100 mi	citywide
	(2)	1948-54		$1,500,000,initially $500,000,annually		1/3 city
Detroit		1968	mercury 675		1 square mi high night crime.	Main streets, residential streets, alleys
Oakland, California		late '60's				
Indianapolis	(1)	1965-68				
	(2)	1959-1960	Mercury 12,000 (also 8,000 nonstreet)	$1,000,000		commercial/residential (near downtown)
Chicago	(1)	1965-1966	Mercury 51,000	$13,000,000	citywide 2,240 miles	17,000 alleys
	(2)	1959				"various districts"

147.

Reported Experience with Street Lighting and Crime (p.4)

(ii) Research Design   (iii) Crime Change Data

	Test Period	Baseline Period	Control Area	(Total) All Crimes (%)	Murder (%)	Rape (%)	Robbery (%)	Assault (%)	Burglary (%)	Larceny (%)	Auto (%)	Other (%)
Cleveland (1)	1966-1971			+80			Purse-snatch-78					
(2)		1965		-17		-44	robbery -27					
Detroit	1968-1969	1965	Similar area, not adjacent	% night crimes Relit -12 Control +14								
Oakland, Cal.				"abrupt drop"								
Indiana-polis (1)	1965-66	Nationwide	Nationwide	test -22 control +6								
	1966-67			test +5.2 control +11		rise be-low nat-ional average						
		adjacent	adjacent	test -84% (N=-225) control: (N=+102)								
(2)				-60								
Chicago (1)	1-3/66 vs 1-3/67	(a) nationwide (b) Chicago streets		test +18 control (a) -15 (b) +33		-40	-15	-35	-53	-16		
(2)							-87, -30, -30					-10

148.

Reported Experience with Street Lighting and Crime (p.5)

(i) Lighting Data

City	Change Date	Lights (type, number)	Cost	Area Size	Area Type
St. Louis (1)	1964				business district
(2)					high crime
New York (1)	1958-59	Mercury	$500,000	111 blocks	Four high crime precincts
(2)	1964	Mercury	28,000,000	citywide 1,100 mi	80% city streets
(3)	1959	Mercury & Incandescent		citywide	400 parks and playgrounds
Boston	1959				Streets with lights in high-crime South End.
McPherson, Kansas (pop 9555)	late '50's		$378,000		residential areas
Flint	1956	Flourescent			Civic Center, 40 dangerous intersections, six miles of downtown streets
Gary	1953-1955	Mercury 5,000		citywide	

Reported Experience with Street Lighting and Crime (p.6)

(ii) Research Design   (iii) Crime Change Data

City	Test Period	Baseline Period	Control Area	(Total) All Crimes(%)	Murder (%)	Rape (%)	Robbery (%)	Assault (%)	Burglary (%)	Larceny (%)	Auto (%)	Other (%)
St. Louis (1)	1964 (9 mos)	1963		(all)-6			-36	-80	-10	purse -50	-29	
(2)	1965 (9 mos)		adjacent	Test:(person) -41 Control:"More than expected"							from auto -24	
New York (1)	1957-1959			(all) -71	all person crimes: -49							juvenile -30
(2)	1960-1964			(felonies) +43								
(3)												Vandalism -80 to -100
Boston			dark streets	More crimes on dark sts. (N=104)								
McPherson, Kansas (pop 9556)									eliminated			peeping: -90
Flint	6 weeks			-60						-80		
Gary							-60	-70				

150.

Reported Experience with Street Lighting and Crime (p.7)

(i) Lighting Data

City	Change Date	Lights (type,number)	Cost	Area Size	Area Type
Kansas City, Missouri	1953			25% of the city	(a) citywide
					(b) main thoroughfares
Chattanooga				12 block	high homicide
Plainfield, New Jersey				60 block	

Reported Experience with Street Lighting and Crime (p.8)

(ii) Research Design

(iii) Crime Change Data

City	Test Period	Baseline Period	Control Area	(Total) All Crimes(%)	Murder (%)	Rape (%)	Robbery (%)	Assault (%)	Burglary (%)	Larceny (%)	Auto (%)	Other (%)
Kansas City, Missouri	1952-1953	1950-51				-05	-09		-06	-46	-17	
Chatta-nooga				-70				-30			-45	
Plainfield, New Jersey									-50			

A-50

152.

The second group of columns, headed "Research Design" indicates the time periods compared during the test period, time periods compared for a baseline (abbreviated as "base"), or prechange crime trends, and the nature of a control area that did not receive relighting.

The third group of columns, headed "Crime Data," gives percentage change in crime rates. This is by type of crime, and where appropriate, dates are given for both test (relit) and control areas and for baseline (prechange) and test periods.

Both periods of time—baseline and test—are composed of two intervals, with crime frequencies determined for each, and a percentage change between the two computed.

For example, the first row on p.1 of the table describes the relighting program in Milwaukee. In Milwaukee, lighting was improved during 1972, using sodium lights. The number of lights was not reported, nor were changeover costs. The change area was 3.5 square miles, and was characterized as having private and multi-unit residences, and also some commercial establishments. The population in this area was characterized as elderly. The Milwaukee data are continued on the second page of the table. The test period compared crime frequencies in the first seven months of 1972 with the first seven months of 1973. A baseline period compared these changes in crime rates to the changes in crime rates in this area from 1971 to 1972. Changes in the relit blocks were compared to changes in a control group composed of blocks adjacent to the relit area. In the relit area, the total of all crimes showed a decline of 25% prior to relighting, and a 15% decline after relighting. By contrast, the control blocks showed an 8% decline in crime before relighting, and an 18% increase afterwards. Changes for individual crimes are not reported.

A.5.3 Kansas City

INTRODUCTION

This major study evaluated the impact of street lighting on street crime in Kansas City, Missouri, assessing the crime rates before and after installation of new street lighting in selected high-crime areas in the area south of the Missouri River. This area included the commerical downtown business district and a nearby area of mixed commercial and residential character.

Between October 1971 and March 1972, 1800 mercury and sodium street lights were installed in approximately 500 blocks in the downtown business district and a mixed residential/commercial neighborhood. These lights replaced the older incandescent illumination in these blocks, as part of an ongoing upgrading or relighting program. These lights were installed at an approximate annual maintenance cost of $140,000 or $4.50 per light per month ($54.00 annually).

In order to assess the impact of street lights on street crime, crime records were examined for the 39 months from January 1970 through March 1973, for a sample of 1427 of the approximately 7000 blocks in Kansas City, Missouri. These sampled blocks included 129 of the 500 relit blocks. The 39 months under investigation were divided into three periods: (1) 21 months preceding relighting (January 1970 - September 1971); (2) 6 months of actual changeover (October 1971 - March 1972); and (3) 12 months following relighting (April 1972 - March 1973). Crime trends were examined for relit blocks and for a sample of nonrelit blocks.

PURPOSE

The objective of this three-phase study was to test the hypothesis that street lighting deters night street crime; to investigate the types and character of crimes that are deterred; and to determine the kinds of neighborhoods in which this deterrent effect occurs.

This investigation is best understood in the context of the dramatic nationwide increase in crime that took place in the nineteen sixties, and subsequent attempts to fight crime by improving street lighting. Across the United States, many cities and towns have initiated major programs of improving their street lighting. Reports from these areas with upgraded lighting generally show that crime is reduced following these lighting programs.

Kansas City was among the cities that experienced this dramatic crime rise in the nineteen sixties, and responded with a program of substantially improved street lighting. The effects of improved lighting in Kansas City, as in other areas, has been to substantially reduce certain target crimes.

The primary target for deterrent effects of street lighting consists of those crimes that occur at night and on the street. For purposes of this study, this class of crimes was limited to crimes that are generally considered serious, and are defined by the FBI's Uniform Crime Reports (UCR) as "Part I Crimes."

Effects of street lighting, or of any other anticrime program, are sometimes investigated only with regard to planned (as opposed to spontaneous) crimes. Planning is thought to include an evaluation of risk, and street lighting is considered to increase the risk or otherwise make crimes harder to commit. In this study, both categories--crimes that are generally considered planned, and crimes that are considered spontaneous--have been investigated. Planned crimes are more likely to be property crimes, while spontaneous crimes are usually "crimes of passion" culminating in attacks on persons.

Effects of street lighting have been analyzed only for those crimes that occur frequently enough to allow meaningful statistical comparisons.

Because the two most serious crimes (murder and rape) occur relatively infrequently, they have been excluded from analysis in this study. This is a limitation in the analysis.

In general, street crimes can be prevented at the level of individual action only by avoiding the streets entirely. This is unsatisfactory and, further, implies that a few offenders would effectively be allowed to terrorize and imprison the remainder of the populace.

Street robbery is of special interest in this study of effects of lighting on crime. It is one of the most frequent of Part I crimes, involves confrontation with violence or the threat of violence, occasional serious injury, and loss of money or goods of value. Since robbery is often a stranger-to-stranger contact, all strangers can be perceived as potential offenders, and use of the streets becomes all the more frightening.

The study also investigated crimes that occurred in nonstreet locations. Since the most frequent of these, burglary, sometimes involves elements of on-street activity, such as the act of illegal entry, or exit with stolen goods, burglary may be responsive to improved street lighting. In fact, a few studies have shown such a deterrent effect for burglary. It should be noted that burglaries have different characteristics, depending on whether the target is a commercial establishment or a residence. For this reason, burglaries are divided into two categories, commercial and residential. Residential burglaries are usually day crimes, as homes are empty when residents go to work, while commercial burglaries are more likely to be night crimes, as businesses close and are vacant for the evening.

SUMMARY OF NIGHT STREET CRIME CHANGES

Prior to relighting, night street crime was increasing in the sample blocks in the relit areas of Kansas City. Following the upgrading period in the relit blocks these crimes decreased dramatically. Crimes involving violence against persons decreased in the relit blocks in ways that were statistically highly significant as contrasted to pre-lighting rates (Table 56). Crimes of violence decreased in relit blocks in ways that were also statistically different from nonrelit blocks. Property crimes showed changes that were consistent with crime-deterrent effects of lighting, but these changes were not as statistically significant levels and may, accordingly, now have been due to lighting, but rather due to change variation (Table 57).

Within relit blocks, changes in night street crime were compared to changes in other night crime--those incidents occurring in nonstreet locations--and other street crime--those incidents occurring during the day (Table 58). This same comparison was performed for nonrelit blocks. For relit blocks, crimes of violence showed greater decreases for the crimes with a night street location relative to the other two

155.

Table 56. Changes in Night Street
Crime in Relit Blocks
(1970-1972)

	Baseline (1970-1971)[1]	Test (1971/1972)[2]	Statistically Significant
Violent Crimes:			
Robbery + Assault	+36% (55/75) [3]	-48% (104/54)	Yes (p<.0001)
Robbery	+34% (35/47)	-52% (67/32)	Yes (p<.0013)
Assault	+40% (20/28)	-41% (37/22)	Yes (p<.05)
Property Crimes:			
Larceny + Auto Theft	+9% (57/62)	-26% (84/65)	No
Larceny	-8% (39/36)	-39% (51/31)	No
Auto Theft	+44% (18/26)	+3% (33/34)	No

Notes:

(1) Baseline (1970/1971) compares nine-month periods: January 1970-
September 1970 and January 1971 - September 1971.

(2) Test (1971/1972) compares twelve-month periods: October 1970 -
September 1971 and April 1972 - March 1973.

(3) Percent change from 1971 to 1972 is indicated by +36%. Numerical
change is indicated by (55/75) or 55 offenses for the 1970 period
and 75 offenses for the 1971 period.

Table 57. Changes in Night Street Crime During [1] the Test Period (1971/1972)

	Relit Blocks	Nonrelit Blocks	Citywide Sample	Statistically Significant [2]
Violent Crimes:				
Robbery + Assault	-48% (104/54) [3]	-7% (167/155)	-20% (362/291)	Yes (p .05)
Robbery	-52% (67/32)	-17% (89/74)	-30% (191/134)	Yes (p .05)
Assault	-41% (37/22)	+4% (78/81)	-8% (171/157)	No (p .10)
Property Crimes:				
Larceny + Auto Theft	-26% (84/65)	-32% (219/149)	-23% (423/325)	No
Larceny	-39% (51/31)	-29% (90/64)	-20% (219/175)	No
Auto Theft	+3% (33/34)	-32% (129/85)	-27% (204/150)	No

Notes:

(1) Test Period (1971-1972) compares twelve-month periods: October 1970 - September 1971 and April 1972 - March 1973.

(2) Statistical tests compare Relit to Nonrelit Blocks.

(3) Percent change from 1971 to 1972 is indicated by -48%. Numerical change is indicated by (104:54) or 104 offenses for the 1971 period and 54 offenses for the 1972 period.

other two locations. For nonrelit blocks, crimes of violence also decreased in night street locations to a greater degree than in the other two locations, but still less than night street crime in relit blocks

Property crimes with a night street location seemed resistant to the effects of lighting, with no major changes observed either from before to after relighting, or between relit and nonrelit blocks. Interestingly, in relit blocks, property crimes in night nonstreet locations decreased as much as those with street locations, while in nonrelit blocks, night nonstreet property crimes did not decrease, although night street property crimes did.

SUMMARY OF DISPLACEMENT OF CRIME

Crime can only be considered *reduced* after a decrease has been found in the target of night street crimes in relit blocks, with no such decrease in control areas and no increase elsewhere, that can be accounted for by displacement shifts.

The primary target of street lighting, within night street crime, is *robbery*, and it is in this crime that street lighting seems to have the most successful impact. Robberies are reduced in the relit blocks more than they are reduced in the controls, or citywide, and more than they are relocated elsewhere.

The response to street lighting of assault is more complicated. The percent decline in the target of night street contacts in the relit blocks is substantial, greater than the percent decline in assault in the controls, and greater than the very small citywide decline. However, the number of assaults that are prevented are more than equalled by increases in the controls, during the test period, particularly when compared to baseline assault rates. It should be noted that while the citywide sample shows a decline in assaults for night street contacts, the UCR reports for the Kansas City SMSA, presented above, show that assault is rising (and is the only serious crime to do so). Thus it may be that within the relit blocks there is an interruption and prevention of assault, with some shift occurring whose magnitude is difficult to determine because of the masking effect of the citywide increase in assault. Thus it cannot be simply determined for assault (unlike robbery), what component of prevented crimes in the relit areas are simply relocated, and which are suppressed. The large side of the displacement profiles for assault suggests that little or none of this crime is suppressed. This is consistent with a general view of assault as a crime of passion, or impulse, less deterrable by rational deterrence (i.e., lighting) than robbery.

This distinction between robbery and assault, in responsiveness to street lighting, is further significant in that the UCR considers these two crimes together, as person or violent crimes. It has been shown above that for national and Kansas City trends, robbery behaves more

like the property crime of larceny that it does like the person crime
of assault. It should be noted that at the level of coding a criminal
contact, there may be a fine line between robbery and assault, since
a robbery attempt may be initiated by an assault, and if interrupted
or successfully resisted, may only be coded as an assault. Similarly,
what is initially an assault may grow into a robbery, as assailants
escalate from an attack to an attack plus theft.

SUMMARY OF COMMERCIAL VS RESIDENTIAL

To further isolate the unique geographical and criminological
aspects of crime that are deterrable by upgraded street lighting, the
entire relit sample was divided into subsamples. One of these sub-
samples contained blocks with a primarily commercial character, and
another subsample contained blocks with a primarily commercial character,
and another subsample contained blocks with a primarily residential
character. Crime rates--defined as crimes per block--for night street
crime for these two subsamples were compared. For the twelve months
prior to relighting, commercial blocks had higher crime rates (roughly
twice as high) than residential blocks. For the twelve months fol-
lowing relighting, rates for the two groups of blocks were considerably
closer. For *violent* crimes, rates were virtually identical, and for
property crimes, the differences were substantially narrowed.

A comparison of changes in night street crime frequencies showed
that commercial blocks had a greater decline than residential blocks,
for all categories of crime under consideration. In comparison with
baseline (1970-1971) data, which showed crime increases, these test
period (1971-1972) declines were even more dramatic. For *violent* crimes,
declines in the test period were near or at statistically significant
levels for *commercial* blocks, while for *residential* blocks, these
changes were significant for robbery but not for assault.

For *commercial* blocks, declines in night street crimes of violence
in relit blocks exceeded changes in the nonrelit blocks. This was true
for residential blocks as well. Property crimes showed generally less
responsiveness to lighting upgrading.

However, within relit commercial blocks, declines in night street
robbery were largely equalled by declines in night nonstreet robbery
and declines in day street robbery. These other changes cannot easily
be attributed to street lighting upgrading. Night street assault showed
a decline, while night nonstreet assault and day street assault showed
increases. Within commercial blocks, then, robberies decline both in
wasy that would be expected in response to street lighting and in ways
or locations that would not be expected.

Within *relit residential* blocks, in contrast to commercial blocks,
night street robberies decline while night nonstreet robberies increase,

and day street robberies decline to a lesser degree. This pattern is consistent with changes that would be expected in response to street lighting.

It may be seen, then, that night street robberies are declining faster in relit commercial blocks than in relit residential blocks, and that declines in each set of blocks are greater for relit than nonrelit blocks. These changes indicate the greater responsiveness to street lighting upgrading for night street robbery in relit commercial blocks than in relit residential blocks. If this is true, then this difference between commercial and residential blocks has important consequences for strategies of where to locate lighting upgrading.

Displacement indications in commercial and residential blocks seem to occur in ways that differentiate between relit and nonrelit areas only for residential blocks, and not for commercial blocks. Violent crimes and larceny retain a night character while other property crimes move to the day.

SUMMARY

Results indicated that crimes of violence--robbery and assault--significantly deterred, while crimes against property were largely unaffected. Prior to relighting, crime rates in blocks with commercial activity were considerably higher than in blocks with residential activity. Following relighting, crime decreased in these commercial blocks somewhat faster than in the residential blocks.

Displacement of crime was also investigated. A small portion of the robberies appeared to relocate into blocks that were not affected by the upgrading program. Displacement of assaults could not be confidently determined because increases in areas not affected by relighting may have been due to the general citywide increase in this offense.

REFERENCES

1. Faucett, R.E. "The New Economics of Roadway Lighting". *Lighting Design and Application,* 3(1), January 1973.

2. De Boer, J.B. "Modern Light Sources for Highways". *Journal of IES,* 3(2), January 1974.

3. Illuminating Engineering Society, *IES Lighting Handbook,* 5th Edition New York, 1972.

4. Collins, B.R., and McVey, C.I. "High-Pressure Sodium Lamps for Use on High-Pressure Mercury Lamp Ballasts", *Lighting Design and Application,* 5(6), June 1975.

5. Hutter, J.A. and Box, P.C., "Roadway Lighting". *Traffic Engineering Handbook,* Institute of Traffic Engineers, Washington, D.C. 1965.

6. Farber, E., Gallagher, V., and Cassel, A. "Interaction Between Fixed and Vehicular Illumination Systems - Phase I Report", DOT, FHWA Contract No. FH11-7599, May 1971.

7. Cassel, A. and Medville, D., *Economic Study of Roadway Lighting, National Cooperative Highway Research Program Report 20,* 1966.

8. Edwards, T.C., Martiney, J.E., McFarland, W.F., and Ross, H.E. "Development of Design Criteria for Safer Luminaire Supports", *National Cooperative Highway Research Program Report,* 77, 1969.

9. Thompson, J.A. and Fansler, B.I. "Economic Study of Luminaire Mounting Heights for Highway Lighting Systems", *Public Roads,* April 1967.

10. Ketvertis, A. and Rauzauskas, S.G.,: Interchange Illumination - Engineering and Economics", *Lighting Design and Application,* 3(10), October 1973.

11. National Safety Council. *Accident Facts,* Chicago, Ill., 1973.

12. AASHTO, *Highway Design and Operational Practices Related to Highway Safety,* 2nd ed., 1974.

13. Stark, R.E. "Studies of Traffic Safety Benefits of Roadway Lighting", *Highway Research Record,* 440, 1973.

14. Tanner, H.J. "Influence of Road Lighting in Traffic Safety and Service" *Australian Road Research Board Proceedings,* 1962.

REFERENCES (CONT'D)

15. Janoff, M.S., Freedman, M. & Koth, B., "Fixed Illumination for Pedestrian Protection: Phase II", *Report No. FHWA RD-74-25*, FIRL, July 1975.

16. Box, P.C. "Comparison of Accidents and Illumination", *Highway Research Record 416*, 1972.

17. Williams, W.L. "Roadway Lighting", *Traffic Engineering*, March, 1970.

18. Box, P.C. "Relationship Between Illumination and Freeway Accidents", *Illumination Engineering*, May/June 1971.

19. Duff, J.T. "Road Lighting and the Role of Central Government", *Lighting Research and Technology*, 6(4), 1974.

20. Seburn, T.J., "Kansas City's New Lighting Begins Saving Lives," *The American City*, July 1948

21. Taragin, A. and Rudy, B.M., "Traffic Operations as Related to Highway Illumination and Delineation," *Highway Research Board Bulletin 255*, 1960.

22. Huber, M.J. and Tracey, J.L., "Effects of Illumination on Operating Characteristics of Freeways," *NCHRP Report #60*, 1968.

23. "Street Lighting, Energy Conservation and Crime", *LEAA Emergency Energy Committee Report No. 2*, March 1, 1974.

24. Southward, Karl. "The Fallacy of Lighting Energy Conservation – A Look at Consumer Usable Fuels", *Lighting Design and Application*, 5(3), March 1975.

25. Lemons, T.M., "Intent and Extent — The Energy Tradeoffs", *Lighting Design and Application*, 5(4), April 1975.

26. Illuminating Engineering Society, *Energy Advisory Committee Report #2*, July 1975.

27. International Commission on Illumination (CIE), Statement on Energy Conservation and Lighting", *Lighting Design and Application*, June 1975. (The Statement is part of CIE's *International Recommendations for Motorway Lighting* now in press).

28. Chamberlain, G.M. "Improve Your City's Street Lighting", *The American City*, November 1974.

29. An Interim Report Relating the Lighting Design Procedure to Effective Energy Utilization", *Lighting Design and Application*, 5(9), September 1975.

REFERENCES (CONT'D)

30. "Public Lighting Can Do Better Than a 10% Cut in Energy Needs",
    Surveyor, 144(4296), October 11, 1974.

31. Blackwell, H.R., "Development of Procedures and Instruments for Visual
    Task Evaluation", *Illuminating Engineering*, 65(4), 1970, 267-291.

32. Farber, E. & Bhise, V., "Development of a Headlight Evaluation Model",
    Transportation Research Board Special Report, 156, 1975, 23-39.

33. Schreuder, D.A., "Symposium on Tunnel Lighting: Fundamental Visual
    Problems in Tunnels", *Lighting Research & Technology*, 7(2), 1975, 85-87.

34. Schreuder, personal communication.

35. Adrian, personal communication.

36. Narisada, K., "Latest Research in Tunnel Lighting in Japan", *Highway Research Circular*, 137, 1972, 9-27.

37. Narisada, K. & Yoshikawa, K., "Lighting Short Tunnels -- Effect of the
    Exit Luminance on the Level of Lighting", paper presented at 18th
    C.I.E. Session, September 1975, London, UK.

38. Finch, D.M. & Palmer, J.D., "Assessment of Nighttime roadway Visi-
    bility", *Highway Research Board Bulletin*, 163, 1957, 1-16.

39. Committee E-1.4.2 on Visual Performance (C.I.E.), "Recommended Method
    for Evaluating Visual Performance Aspects of Lighting", *C.I.E. Publi-
    cation No. 19 (Proposed)*, July 1971.

40. Finch, D.M., "Some Factors Influencing the Night Visibility of Roadway
    Obstacles", *Illuminating Engineering*, 52(3), 1957, 120-130.

41. Blackwell, O. M., "A Prescription for Roadway Lighting", *Lighting Design & Application*, 4(2), 1974, 38-41.

42. Martin, M.D., "Standardization of Visual Tasks and Measures", *U.S.
    Army Human Engineering Laboratory Technical Note*, 2-73, March 1973.

43. Blackwell, H. R. & Blackwell, O. M., "A Static Scale-Model Simulator
    for the Study of Visibility and Highway Lighting", *Highway Research
    Record*, 377, 1971, 24-31.

REFERENCES (CONT'D)

44. Blackwell, O.M. & Blackwell, H.R., "Night Visibility under Different Systems of Fixed Roadway Lighting: A Progress Report", *Transportation Research Board Special Report*, 156, 1975, 1-10.

45. Committee E-3.3.1. (C.I.E.), "International Recommendations for the Lighting of Public Thoroughfares", *C.I.E. Publication No. 12*, 1965.

46. Blackwell, H.R., personal communication.

47. Mortimer, R. G., "Field and Computer-Simulated Evaluation of Head Lamp Beams", *Transportation Research Board Special Report*, 156, 1975, 64-73.

48. Gallagher, V.P., Koth, B. W. & Freedman, M., "The Specification of Streetlighting Needs", *Report No. DOT-TST-72-1*, FIRL, June 1975.

49. Baerwald, J. E. (ed.), *Traffic Engineering Handbook*, Institute of Traffic Engineers, Washington, D.C. 1975, p. 616.

50. American Association of State Highway Officials, *A Policy on Geometric Design of Rural Highways*, AASHO, Washington, D.C. 1966.

51. Wright, R., et. al., "The Impact of Street Lighting on Street Crime, May 1974, University of Michigan.

52. Department of Intergovernmental Fiscal Liaison, Milwaukee, Wisconsin, "Milwaukee High Intensity Street Lighting Program", December 1973 and July 1974.

53. The City Commission of Miami, Florida, "Miami Relights", December 1973.

54. Inskeep, N.R. and Goff, C., "A Preliminary Evaluation of the Portland Lighting Project, Oregon Law Enforcement Council, August 1974.

OTHER REFERENCES EMPLOYED BUT NOT CITED

"Miami Relights", *Public Works*, May 1974.

Johnson, P.J., "Streetlighting Brings Results", *Nations Cities*, August, 1973.

LEAA Emergency Energy Report #2 - "Street Lighting, Energy Conservation and Crime", March 1974.

Basaran, S., "HPS for Washington, D.C.", *LD&A*, April 1975.

Matheny, J.E., "Ten Year Program Upgrades Richmond's Street Lights", November 1974.

I.E.S., "Public Lighting Needs", September 1966.

APPENDIX B

PHOTOMETERED SITE INVENTORY

This appendix contains a full listing of the 84 sites photometered as part of this research.   The data include

        Site Description
        Area Type
        Population Density
        Lighting System Configuration
        Lighting System Spacing
        Number of Roadway Lanes
        Road Width
        Number of Roadway Directions
        Luminaire Type

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
1	HUNTING PARK Macalester to Front	OBD	M	One-sided (S)	180	4	60.2	2	M
2	HUNTING PARK I to K	OBD	M	One-sided (S)	185	4	60.0	2	M
3	21st Race to Arch	CBD	M	Ond-sided (E)	110	2	25.9	1	M
4	56st *SPLIT* Market to Chestnut	RF	H	One-sided (W)	88/106	2	33.8	1	M
5	COBBS CREEK Market to Cedar	RF	H	Staggered	188	4	50.5	2	M
6	ROBBINS Bustleton to Leonard	RF	M	One-sided	164	2	36.0	1	M
7	CHELTENHAM Seven Oaks to Tookany	OBD	M	Staggered	284	4	55.0	2	M
8	LINDBERGH Island to 70th	RF	L	Opposite	116	6 +med.	72.5	2	M
9	19th Race to Arch	CBD	M	Ond-sided (E)	110	2	26.0	1	HPS
10	CEDAR *SPLIT* 51st to 52nd	RF	H	One-sided (N)	116/116	2	34.1	2	HPS

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
11	BELMONT Conshohocken to Monument	RF	L	Staggered	240	4	59.7	2	HPS
12	ARCH 19th to 20th	CBD	M	Staggered	264	2	36.1	1	HPS
13	RACE 13th to Camac	CBD	M	Staggered	236	2	25.9	1	HPS
14	WALNUT 13th to Broad	CBD	M	Staggered	186	2	25.6	1	HPS
15	22nd Arch to Race	CBD	M	Staggered	224	3	42.0	1	HPS
16	21st Spruce to Pine	CBD	H	One-sided (E)	124	1	26.1	1	HPS
17	13th South to Pine	CBD	M	Staggered	100	2	26.2	1	HPS
18	22nd Pine to Spruce	CBD	M	One-sided (E)	100	2	32.8	1	HPS
19	16th Pine to Spruce	CBD	H	One-sided (E)	106	2	25.9	1	HPS
20	9th Spruce to Pine	CBD	M	One-sided (W)	138	2	25.9	1	HPS

168.

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
21	CHESTNUT 3rd to 5th	CBD	L	Staggered	266	2	26.1	1	HPS
22	12th Pine to Spruce	CBD	M	One-sided (W)	140	2	25.9	1	HPS
23	LOCUST 9th to 10th	CBD	H	Staggered	210	2	26.2	1	HPS
24	S. BROAD Wash. to Carpenter	CBD	H	Staggered	136	4 + med.	66.9	2	M
25	S. BROAD Ludlow to South	CBD	H	Staggered	136	4 + med.	66.9	2	M
26	N. BROAD Callowhill to Spring Garden	CBD	L	Staggered	132	4 + med.	68.9	2	HPS
27	N. BROAD	OBD	H	Staggered	132	4 + med.	68.9	2	HPS
28	W. MARKET 42nd to Preston	OBD	M	Staggered	228	4	59.9	2	M
29	PINE (SOCIETY HILL) 4th to 5th	RF	H	Staggered	70	2	26.2	1	INC
30	AVE. OF STATES(CHESTER) 4th to 3rd	CBD	L	Opposite	66	2	27.2	1	M

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
31	9th (CHESTER) Penn to Sproul	CBD	L	One-sided (S)	142	2	36.3	2	M
32	7th (CHESTER) Penn to Sproul	CBD	L	One-sided (W)	120	2	36.1	2	M
33	5th (CHESTER) Penn to Edgemont	CBD	L	One-sided (N)	114	2	36.1	2	M
34	RACE 18th to 16th	CBD	L	Staggered	254	2	26.1	1	HPS
35	WASHINGTON (CHELT.) Wister to Shoppers	RF	L	Staggered	359	4	50.4	2	M
36	EASTON (CHELT.) Wesley to Springhouse	OBD	L	Staggered	224	2	49.0	2	M
37	LIMEKILN (CHELT.) Easton to Harrison	RF	L	Staggered	292	2	49.9	2	M
38	7th Pine to Spruce	RF	H	Staggered	72	2	25.9	1	INC
39	4th Pine to Spruce	RF	M	Staggered	74	2	25.9	1	INC
40	UPSAL Emlen to Cherokee	RF	M	Staggered	258	2	44.0	2	M

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
41	23rd Locust to Spruce	CBD	H	One-sided (W)	106	2	26.2	1	HPS
42	18th Rittenhouse to Walnut	CBD	H	One-sided (E)	154	2	25.8	1	HPS
43	SPRINGGARDEN 17th to 18th	RF	M	Staggered	184	4	66.3 + med.	2	HPS
44	SPRUCE 19th to 20th	CBD	H	One-sided (S)	150	2	25.9	1	HPS
45	LOCUST 22nd to 21st	CBD	H	Staggered	212	2	25.9	1	HPS
46	33rd Market to Arch	OBD	L	Staggered	192	2	33.8	1	HPS
47	OREGON 21st to 23rd	OBD	H	Staggered	205	4	73.2 + med.	2	HPS
48	SPRINGGARDEN 7th to 8th	OBD	L	Staggered	172	4	72.2 + med.	2	HPS
49	ARAMINGO Butler to Wheatsheaf	RF	L	Staggered	196	4	33.1 + med.	2	HPS
50	CASTOR grade to Almond	OBD	L	Staggered	196	2	50.2	2	HPS

171.

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
51	HAVERFORD 50th to 51st	OBD	H	One-sided (S)	134	2	44.3	2	HPS
52	SNYDER 4th to 3rd	OBD	H	Staggered	278	2	45.3	2	HPS
53	WASHINGTON 23rd to 22nd	OBD	M	Staggered	200	4	68.9	2	HPS
54	TACONY STATE Ashburner to Holmesburg	RF	L	Staggered	210	4	60.4	2	HPS
55	COMLY Norcom to Thornton	RF	L	Staggered	186	4	72.2 + med.	2	HPS
56	GRANT Ashton to Blue Grass	OBD	L	Staggered	210	4	65.3	2	HPS
57	COTTMAN Whitaker to Tabor	RF	M	Staggered	276	4	59.7	2	HPS
58	TORRESDALE Bleigh to Shelmire	OBD	M	One-sided (W)	204	2	48.2	2	HPS
59	CHELTENHAM Ivy Hill to Roumfort	OBD	H	Staggered	182	2	64.3	2	M
60	5th Nedro to Grange	OBD	M	One-sided (W)	186	2	50.2	2	HPS

172.

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
61	RISING SUN Knorr to Longshore	OBD	L	Staggered	248	2	44.0	2	HPS
62	COTTMAN Bustleton to Castor	OBD	M	Staggered	220	4	53.8 + med.	2	HPS
63	57th Walnut to Sansom	OBD	H	Staggered	206	2	44.0	2	HPS
64	52nd Cedar to Catherine	OBD	H	staggered	288	2	49.5	2	HPS
65	ARCH 8th to Broad	CBD	L	Staggered	264	2	36.1	1	HPS
66	GRANT Ashton to Leon	RF	L	Staggered	210	4	65.3	2	HPS
67	CASTOR Wakeling to Pratt	RF	M	One-sided (W)	270	2	44.0	2	HPS
68	RISING SUN Erie to 6th	RF	M	One-sided (E)	100	2	39.7	2	HPS
69	FRONT Clearfield to Indiana	OBD	H	One-sided (E)	240	2	34.1	1	HPS
70	CHESTNUT 40th to 41st	RF	H	Staggered	264	3	44.5	1	HPS

173.

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
71	13th Diamong to Susquehanna	RF	H	One-sided (E)	167	2	26.2	1	HPS
72	16th Berks to Norris	OBD	H	One-sided (W)	100	2	24.3	1	HPS
73	FRONT Huntington to Cumberland	OBD	M	One-sided (W)	128	2	34.1	1	HPS
74	FAIRMOUNT 18th to 17th	RF	H	Staggered	270	2	47.9	2	HPS
75	FRANKFORD Placid to Megargee	OBD	L	One-sided (W)	228	4	46.3	2	HPS
76	TORRESDALE Celtenham to Robbins	OBD	M	One-sided	205	2	48.2	2	HPS
77	15th Montgomery to Girard	RF	H	One-sided	100	2	24.3	1	HPS
78	SPRINGGARDEN 18th to 23rd	RF	M	Staggered	184	4	66.3 + med.	2	HPS
79	OLD YORK Hunting Park to Lycom.	RF	M	One-sided (W)	110	2	38.1	2	HPS
80	HARTEL Veree to Rising Sun	RF	L	One-Sided (S)	108	2	36.1	2	HPS

174.

PHOTOMETERED SITE INVENTORY

No.	Site	Area Type	Density (Persons/ sq. Mile)	Configuration	Spacing (Ft.)	No. of Lanes	Width (Ft.)	No. of Directions	Luminaire
81	BUSTLETON Shelmire to Oakmont	OBD	L	Staggered	250	4	60.0	2	HPS
82	CASTOR Shelmire to Faunce	OBD	L	Staggered	196	4	66.9	2	HPS
83	E. MARKET Front to 5th	CBD	L	Staggered	228	4	59.9	2	M
84	BELMONT Parkside to Girard	RF	L	Staggered	240	4	59.7	2	HPS

APPENDIX C
REGRESSION ANALYSIS

C.1 VARIABLES

The objective of this part of the research was to statistically relate the accident history variables to visibility, demographic and socio-economic variables. The specific variables studied are described in Section 5.

C.2 REGRESSION ANALYSES

The means and standard deviations of all variables are presented in Table 58, and the intercorrelation matrix of all accident history variables is presented in Table 59. As shown in Table 59, three of the chosen criteria (Number of Accidents, Number of Vehicles Involved, and Number of Property Damage Accidents) were highly correlated. However, the analyses proceeded ignoring this fact on the possibility that the results of the regression analyses for these three criteria would not necessarily be identical. Based on the intercorrelation matrices of the visibility predictors (shown in Table 60 and demographic-socio-economic predictors and traffic volume (shown in Table 61), as well as the predictor-criterion correlations (shown in Tables 62 and 63), three variables were eliminated prior to performing any of the regression analyses. For the visibility variables, HFC50 was dropped because of a 0.96 correlation with HFC15, and WDVI was dropped because of a .97 correlation with VI15. In the former case, the retained visibility variable was more highly correlated with the criteria, while in the latter case the retained variable was less complex (and easier to work with both photometrically and mathematically). In addition, since only 2 dummy variables are necessary to capture all of the information in 3 categories, one of the area designation dummy variables was eliminated. Specifically, OBD vs. Other was dropped because of its lower correlations with the criteria in comparison to the other 2 dummy variables.

Preliminary Regression Analysis

Initially, each of the four criteria was regressed on the remaining 17 predictors stepwise with the following order: 2 area dummy variables, Density plus 8 census variables, 4 visibility variables (LTRAP plus 15th percential values for HFC, VI, and DVI), and 2 additional visibility variables (50th percentile values for VI and DVI). The reason for separating the 15th percentile visibility variables from the 50th percentile visibility variables was the high correlation among the respective measures (.81 for VI measures and .74 for DVI

Table 58.
MEANS AND STANDARD DEVIATIONS

VISIBILITY	MEAN	S.D.
HFC_{50}	2.08	1.33
HFC_{15}	1.16	1.00
L_{TRAP}	.79	.51
VI_{50}	10.44	4.21
VI_{15}	4.62	3.88
DVI_{50}	8.28	3.97
DVI_{15}	2.98	2.45
WDVI	4.04	3.22

ACCIDENT HISTORY	MEAN	S.D.
No. Accidents	3.83	4.38
No. Vehicles Involved	7.85	9.31
No. Pedestrian Injuries	.13	.46
No. Vehicle Occupant Injuries	.61	1.68
No. Pedestrian Fatalities	.02	.14
No. Vehicle Occupant Fatalities	.04	1.68
No. Property Damage Accidents	3.48	3.97
No. Total Injuries	.74	1.74
No. Total Fatalities	.06	.28
No. Pedestrian Injuries plus Fatalities	.15	.47
No. Vehicle Occupant Injuries plus Fatalities	.65	1.68
No. Total Injuries plus Fatalities	.80	1.76
Composite Severity	19.66	51.77

Total Number of Accidents: 322

DEMOGRAPHIC-SOCIOECONOMIC	MEAN	S.D.
CBD vs. Other	.35	.48
OBD vs. Other	.32	.47
RF vs. Other	.33	.47
Density	21,644.	13,650.
% Non-Spanish Speaking White	.71	.32
% Native of Native Parentage	.72	.15
Median Income	10,231.	3,590
% High School Graduates	.47	.19
% White Collar	.58	.21
Persons per Household	2.45	.62
% Young	.18	.09
% Old	.27	.08
Traffic Volume	13,107	8245

177.

Table 59.

INTERCORRELATION MATRIX OF ACCIDENT HISTORY VARIABLES
(DRY WEATHER - TOTAL ACCIDENTS)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) No Accidents	--												
(2) No Vehicles Involved	.99	--											
(3) No. Pedestrian Injuries	.14	.08	--										
(4) No. Vehicle Occupant Injuries	.23	.21	.00	--									
(5) No. Pedestrian Fatalities	-.07	-.08	-.04	.04	--								
(6) No. vehicle Occupant Fatalities	-.07	-.09	-.04	-.06	.02	--							
(7) No. Property Damage Accidents	.89	.89	.13	.28	-.07	-.06	--						
(8) No. Total Injuries	.26	.23	.27	.96	.03	-.07	.30	--					
(9) No. Total Fatalities	-.10	-.12	-.06	-.03	.50	.85	-.09	-.04	--				
(10) No. Pedestrian Injuries plus Fatalities	.11	.05	.95	.02	.26	-.05	.11	.27	.09	--			
(11) No. Vehicle Occupant Injuries plus Fatalities	.22	.20	.00	.99	.04	.08	.27	.95	.09	.01	--		
(12) No. Total Injuries plus Fatalities	.24	.21	.26	.95	.11	.07	.29	.99	.12	.28	.96	--	
(13) Composite Severity	.04	.01	.02	.24	.49	.81	.06	.24	.96	.17	.35	.38	--

Table 60.

INTERCORRELATION MATRIX OF VISIBILITY VARIABLES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) HFC_{50}	--							
(2) HFC_{15}	.96	--						
(3) L_{TRAP}	.82	.82	--					
(4) VI_{50}	.55	.52	.80	--				
(5) VI_{15}	.50	.53	.70	.81	--			
(6) DVI_{50}	.35	.32	.57	.75	.49	--		
(7) DVI_{15}	.37	.38	.61	.73	.70	.74	--	
(8) WDVI	.50	.53	.73	.84	.97	.59	.81	--

Table 61.

INTERCORRELATION MATRIX OF DEMOGRAPHIC - SOCIOECONOMIC VARIABLES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Central Business District vs. Other	--											
(2) Outlying Business District vs. Other	-.50	--										
(3) Residential Fringe vs. Other	-.51	-.49	--									
(4) Density	-.11	.18	-.07	--								
(5) % Non-Spanish Speaking White	.13	-.02	-.11	-.32	--							
(6) % Native of Native Parentage	-.28	.11	.18	.34	-.67	--						
(7) Median Income	.15	-.26	.10	-.15	.59	-.47	--					
(8) % High School Graduates	.24	-.27	.02	-.14	.52	-.36	.70	--				
(9) % White Collar	.39	-.30	-.10	-.22	.64	-.56	.71	.89	--			
(10) Persons per Household	-.74	.41	.34	.12	-.26	.35	-.24	-.53	-.68	--		
(11) % Young	-.62	.31	.32	.12	-.45	.44	-.34	-.63	-.76	.89	--	
(12) % Old	.48	-.16	-.32	-.17	.31	-.62	.36	.23	.43	-.57	-.60	--
(13) ADT	-.21	.09	.12	-.04	-.03	-.09	-.08	-.08	-.06	.24	.20	-.07

180.

Table 62.

CORRELATIONS BETWEEN ACCIDENT HISTORY VARIABLES AND VISIBILITY VARIABLES

	HFC_{50}	HFC_{15}	L_{TRAP}	VI_{50}	VI_{15}	DVI_{50}	DVI_{15}	$MDVI$
No. Accidents	.18	.20	.08	.06	-.10	-.04	-.16	-.09
No. Vehicles Involved	.18	.19	.07	.05	-.11	-.04	-.18	-.11
No. Pedestrian Injuries	.20	.22	.21	.16	.24	.09	.16	.25
No. Vehicle Occupant Injuries	-.05	-.04	-.14	-.03	-.11	-.02	-.12	-.14
No. Pedestrian Fatalities	-.19	-.15	-.16	-.17	-.11	-.18	-.09	-.12
No. Vehicle Occupant Fatalities	.21	.21	.23	.13	.11	.22	.32	.17
No. Property Damage Accidents	.03	.02	-.03	.04	-.12	-.06	-.17	-.12
No. Total Injuries	.00	.02	-.08	.02	-.05	.01	-.07	-.06
No. Total Fatalities	.08	.10	.11	.02	.04	.09	.23	.08
No. Pedestrian Injuries plus Fatalities	.13	.16	.15	.11	.20	.03	.13	.21
No. Vehicle Occupant Injuries plus Fatalities	-.03	-.01	-.10	-.01	-.10	.01	-.07	-.11
No. Total Injuries plus Fatalities	.01	.03	-.06	.02	-.04	.02	-.04	-.05
Composite Severity	.08	.11	.09	.03	.02	.09	.19	.06

Table 63.

CORRELATIONS BETWEEN ACCIDENT HISTORY VARIABLES AND DEMOGRAPHIC-SOCIOECONOMIC VARIABLES

	% Old	% Young	Persons per Household	% White Collar	% High School Graduates	Median Income	% Native of Native Parentage	% Non-Spanish Speaking White	Density	RF vs. Other	OBD vs. Other	CBD vs. Other
No. Accidents	-.02	-.07	-.14	.00	.01	-.13	.09	-.17	.20	-.21	-.05	.25
No. Vehicles Involved	-.03	-.07	-.13	-.02	-.01	-.14	.11	-.18	.21	-.18	-.07	.24
No. Pedestrian Injuries	-.15	.16	.05	-.12	-.09	-.14	.11	-.25	.20	-.02	.06	-.03
No. Vehicle Occupant Injuries	-.07	.09	.14	-.03	-.01	.01	.06	-.03	-.05	-.13	.16	-.02
No. Pedestrian Fatalities	.07	.02	.08	.08	.10	.24	-.12	.06	-.07	.12	-.10	-.02
No. Vehicle Occupant Fatalities	-.08	-.27	-.18	.14	.26	-.19	-.01	-.18	-.11	-.11	.09	.02
No. Property Damage Accidents	-.08	-.04	-.06	-.01	.05	-.10	.10	-.10	.29	-.13	-.02	.15
No. Total Injuries	-.11	.13	.15	-.06	-.03	-.03	.09	.10	.00	-.13	.17	-.03
No. Total Fatalities	-.03	-.22	-.12	.07	.27	-.04	-.07	-.23	-.13	-.03	.03	.01
No. Pedestrian Injuries plus Fatalities	-.12	.16	.08	-.09	-.05	-.06	.06	-.20	.17	.01	.02	-.04
No. Vehicle Occupant Injuries plus Fatalities	-.08	.05	.11	-.01	.03	-.02	.06	-.02	-.07	-.15	.17	-.02
No. Total Injuries plus Fatalities	-.11	.09	.13	-.03	.02	-.04	.08	-.08	-.02	-.14	.17	-.03
Composite Severity	-.07	-.18	-.08	.15	.26	-.05	-.04	.06	-.10	-.08	.07	.01

measures) and the generally lower correlations with the criteria for the 50th percentile variables as compared to the 15th percentile variables.

Table 64 summarizes the successive multiple R values obtained from the four initial preliminary regression analyses (Set A) and significance tests on each multiple R. The improvement in the multiple R by adding the set of visibility variables to the 11 demographic-socioeconomic variables was statistically non-significant for the prediction of all 4 criteria. This result suggests that over and above any effects attributable to demographic-socioeconomic characteristics, the 4 visibility variables did not increase the prediction of accident history variables. By themselves, the 4 visibility variables were related at the .05 level to Number of Accidents (R=.34) and Number of Vehicles Involved (R=.35), but not related to Number of Property Damage Accidents (R=.21) and Composite Severity (R=.28).

Table 64.

SUCCESSIVE MULTIPLE R'S IN REGRESSION OF EACH OF FOUR CRITERIA
ON FOUR SETS OF PREDICTORS (SET A ANALYSES)

	No Accidents	No Vehicles	No. Property Damage Accidents	Composite Severity
2 Area Dummy Variables	.27**	.25**	.16	.08
9 Density + Census Variable	.41	.41	.43*	.53***
4 Visibility Variables	.50*	.51*	.50*	.60****
2 Visibility Variables	.57***	.58***	.59***	.60***

* $p < .20$

** $p < .10$

*** $p < .05$

**** $p < .01$

It was clear from the above analyses that some of the gains in the multiple R's were attributable to "suppression" (the effect of including predictors that are more highly correlated with other predictors than with the criteria). Furthermore, since the set of 17 predictors for

each criterion contained many highly correlated predictors, it was necessary to eliminate predictors in order to insire higher cross-validities.

Primary Regression Analyses

Another series of regression analyses (Set B) were performed eliminating dummy area and census variables that had correlations with each criterion with absolute values lower than .0948 (critical value at $p <$ .20 one-tailed) as well as other variables that had predictor-criterion correlations that were intuitively unreasonable (i.e., sign opposite from that expected). HFC15 and LTRAP, which had positive correlations with the criteria (negative correlations would have been expected) were kept in these analyses and allowed to enter last into the regression solutions. Following these regression analyses, further variables were eliminated (for Set C analyses) if the F test on the increase in the multiple R at the time of entering the Set B solution had a value less than 1.00. Lastly, Set D analyses were performed deleting from the Set C regression solutions those variables which, according to the F tests, if dropped from the solutions, would not lead to a statistically significant loss ($p < .05$) in predictability. A-tempts were made in these sets of analyses to keep at least one of the visibility variables in each solution.

The results of the Sets B through D regression analyses are summarized in Table 65. (In this table and succeeding tables, predictor-criterion correlations (r), standardized regression weights (B), and multiple R's are presented. The tests associated with each B value in these tables concerns the loss in predictability if each predictor were individually dropped from the full regression equation). The Set D analyses are of greatest interest. For predicting Number of Accidents, the regression equation, with a multiple R of .47, reveals that a greater number of accidents occur in CBD areas of high population density with high HFC15 and low VI15. Using only three predictors, greater numbers of vehicles involved and greater numbers of property damage accidents were obtained in CBD areas of high density with low VI15. The respective multiple R's both statistically significant at the .01 level, were .42 and .41. For predicting composite severity, the results were not easily interpretable; specifically, higher composite severity was obtained for sites around which resided high percentages of High School Graduates and for which high DVI15 was obtained.

Additional Regression Analyses

A series of analyses for the conditions of Dry Weather-Single Vehicle, Dry Weather-Multiple Vehicle, and Wet Weather-Total Vehicle accidents were also performed to parallel the set C analyses for Dry Weather - Total Vehicle accidents. It is clear from inspection of Table 66 that the results for Dry Weather - Total Vehicles accidents were not quite the same as those for Dry Weather - Single Vehicle and

Table 65.

PREDICTOR-CRITERION CORRELATIONS AND STANDARDIZED REGRESSION WEIGHTS
FROM SETS B THROUGH D ANALYSES

	NUMBER OF ACCIDENTS			
	r	B (Set B)	B (Set C)	B (Set D)
Central Business District	.25***	.28*	.31****	.29****
Residential Fringe	-.21***	-.18		
Density	.20***	.22**	.24***	.27***
% Non-Spanish Speaking White	-.17**	-.09	-.08	
Median Income	-.13*	.01		
Persons per Household	-.14*	.03		
HFC_{15}	.20***	.20	.25**	.29***
L_{TRAP}	.08	.07		
VI_{15}	-.10*	-.33**	-.35****	-.37****
DVI_{15}	-.16**	-.07		
R		.48***	.47****	.47*****

NUMBER OF VEHICLES INVOLVED

	r	B (Set B)	B (Set C)	B (Set D)
Central Business District	.24***	.31**	.35****	.34****
Residential Fringe	-.18**	-.04		
Density	.21***	.25***	.25***	.30****
% Non-Spanish Speaking White	-.18**	-.08	-.17*	
% Native of Native Parentage	-.11*	-.02		
Median Income	-.14*	-.02		
Persons Per Household	-.13*	.05		
HFC_{15}	.19***	.17		
L_{TRAP}	.07	.12		
VI_{15}	-.11*	-.35**	-.26***	-.25***
DVI_{15}	-.18**	-.09		
R		.49***	.45****	.42****

185.

Table 65. (cont.)
NUMBER OF PROPERTY DAMAGE ACCIDENTS

Central Business District	.15**	.24**	.26***	.25***
Residential Fringe	-.13*	-.04		
Density	.29****	.33****	.32****	.36*****
% Non-Spanish Speaking White	-.18**	-.22	-.14	
% Native of Native Parentage	.10*	-.13		
Median Income	-.10*	-.03		
HFC$_{15}$	.02	-.08		
L$_{TRAP}$	-.03	.09		
VI$_{15}$	-.12*	-.29*	-.26***	-.25***
DVI$_{15}$	-.17**	-.03		
R		.45**	.44****	.41****

COMPOSITE SEVERITY

% High School Graduates	.26****	.77****	.32***	.29****
% White Collar	.15**	-.65***		
% Young	-.18**	-.24*	.01	
HFC$_{15}$	.11*	.25*	.12	
L$_{TRAP}$	.04	-.01		
VI$_{15}$	.02	-.34***		
DVI$_{15}$	.19***	.36***	.19*	.23***
R		.49****	.36***	.35****.

*p < .20
**p < .10
***p < .05
****p < .01
*****p < .001

Table 66.
RESULTS OF COMPARATIVE ANALYSES PARALLELING SET C ANALYSES OF DRY WEATHER -
TOTAL VEHICLE ACCIDENTS

	Dry-Single		Dry-Multiple		Wet-Total	
No. of Accidents	NO. ACCIDENTS					
	r	B	r	B	r	B
Central Business District	.09	.18*	.32****	.33****	-.05	-.07
Density	.28****	.27***	.07	.16*	.27****	.18*
% Non-Spanish Speaking White	-.23***	-.20*	-.07	.04	-.27****	-.14
HFC_{15}	.05	-.02	.27***	.42*****	.24***	.13
VI_{15}	-.03	-.13	-.12*	-.45*****	.21***	.11
R		.37***		.54*****		.38***
No. Vehicles	NO. VEHICLES					
Central Business District	.08	.18*	.32****	.42*****	-.10*	-.08
Density	.27****	.26***	.10*	.17*	.33****	.23***
% Non-Spanish Speaking White	-.26****	-.21**	-.06	-.09	-.28****	-.18*
VI_{15}	-.05	-.16*	-.14*	-.28***	.20***	.15*
R		.39***		.44****		.41****
No. Property Damage	NO. PROPERTY DAMAGE					
Central Business District	.04	.12	.23***	.34****	-.17**	-.16*
Density	.29****	.28***	.21***	.28***	.35*****	.26***
% Non-Spanish Speaking White	-.21***	-.15*	-.10*	-.09	-.24***	-.12
VI_{15}	-.05	-.15*	-.16**	-.31****	.19***	.16*
R		.36***		.44****		.42****
	COMPOSITE SEVERITY					
% High School Graduate	.21***	.23*	.16**	.25**	.11*	.17
% Young	-.22***	-.09	.02	.18	.03	.14
HFC_{15}	.19***	.15*	-.12*	-.03	-.14*	-.12
DVI_{15}	.29****	.26***	-.12*	-.08	.00	.06
R		.42****		.24		.20

*$p < .20$
**$p < .10$
***$p < .05$
****$p < .01$
*****$p < .001$

187.

Dry Weather - Multiple Vehicles accidents. In particular, the relation-
ships between both Density and % Non-Spanish Speaking White with the
criteria were generally stronger for the Dry Weather - Single Vehicle
accidents, while the relationship between the CBD vs Other and the visi-
bility variables were stronger for the Dry Weather - Multiple Vehicles
accidents. These results suggest that the aggregating of the various
accident conditions into the Dry Weather - Total Vehicle accidents may
have distorted the actual importance of the various predictors for pre-
dicting the criteria. In the analyses for which Wet Weather - Total
Vehicle accidents were predicted, the roles of Density and census vari-
ables were similar to those in Dry Weather - Total Vehicle accident
analyses, i.e., more accidents for neighborhoods with higher population
density and low proportions of Non-Spanish Speaking Whites. This tends
to confirm the role of demographic-socioeconomic variables in the pre-
diction of accidents under any weather condition. Interestingly, in
the Wet Weather - Total Vehicle accident analyses, higher VI15 was
associated with higher numbers of accidents, vehicles involved, and
property damage accidents. However, in the regression analyses, these
latter relationships were somewhat weaker.

Using the final solutions from the set D analyses, additional re-
gression analyses were performed in order to compare the 15th percentile
visibility variables, where appropriate, to the 50th percentile visi-
bility variables in combination with the other predictors for predict-
ing the four criteria (shown in Table 67). In every case, the multiple
R's were higher for the equations composed on 15th percentile visibility
variables. Further analyses were performed to compare 15th percentile
VI and DVI to 50th percentile VI and DVI in combination with CBD vs
Other and Density. These results are summarized in Table 68. Consis-
tently, higher multiple R's were obtained for the equations composed of
15th percentile visibility variables (VI and DVI). Lastly, analyses
were performed to compare 15th percentile values of HFC, VI, and DVI in
combination with CBD vs Other and Density. Those results are shown in
Table 69. Clearly, the best results were obtained for the equation
using VI15, followed by the equation using DVI15, with the equation
using HFC15 poorest.

In general, it was found that values of Accident History variables
can be predicted from knowledge of neighborhood demographic-socio-
economic and visibility variables. From the final equations derived,
both types of variables are needed for maximizing predictions. Insofar
as the squared multiple correlation coefficient ($R2$) indicates the pro-
portion of variance in the criterion accounted for by the predictors,
the various results obtained revealed that, at best, in the final re-
gression solutions only .22 (.47 squared) of the variance in any of the
criteria was accounted for. This suggests that there are likely a large
number of factors influencing the accident statistics that were not
studied in this experiment. Nevertheless, the results of the final
solutions revealed better-than-chance predictions and a good start to-
ware predicting accident frequency.

Table 67.
SUMMARY RESULTS OF ANALYSES TO COMPARE SET D CONDITIONS WITH 15TH PERCENTILE
AND 50TH PERCENTILE VISIBILITY VARIABLES

	NO. ACCIDENTS				
	r	B		r	B
Central Business District	.25***	.29****	CBD	.25***	.26***
Density	.20***	.27***	DENS	.20***	.23***
HFC_{15}	.20***	.29***	HFC_{50}	.18***	.17*
VI_{15}	-.10*	-.37****	VI_{50}	.06	-.12
R		.47*****			.37***

	NO. VEHICLES				
	r	B		r	B
Central Business District	.24***	.34****	CBD	.24***	.28***
Density	.21***	.30****	DENS	.21***	.25***
VI_{15}	-.11*	-.25***	VI_{50}	.05	-.04
R		.42****			.34***

	No. Property Damage				
	r	B		r	B
Central Business District	.15**	.25***	CBD	.15**	.19**
Density	.29****	.36*****	DENS	.29****	.32****
VI_{15}	-.12*	-.25***	VI_{50}	.04	-.05
R		.41****			.34***

	COMPOSITE SEVERITY				
	r	B		r	B
% High School Graduates	.26****	.29***	%HSG	.26****	.30****
DVI_{15}	.19***	.23***	DVI_{50}	.09	.16*
R		.35****			.31***

*p < .20
**p < .10
***p < .05
****p < .01
*****p < .001

189.

Table 68.
SUMMARY RESULTS OF ANALYSES COMPARING 15TH AND 50TH PERCENTILE VALUES
OF VI AND DVI

	NO. ACCIDENTS				
	r	B		r	B
Central Business District vs. Other	.25***	.33****	CBD vs.OTHER	.25***	.28***
Density	.20***	.28***	Density	.20***	.24***
VI_{15}	-.10*	-.21	VI_{50}	.05	-.03
DVI_{15}	-.16**	-.03	DVI_{50}	-.04	.00
R		.40****			.34**
	NO. VEHICLES				
	r	B		r	B
Central Business District vs. Other	.24***	.33****	CBD vs. OTHER	.24***	.28***
Density	.21***	.29****	Density	.21***	.25***
VI_{15}	-.11*	-.22*	VI_{50}	.05	-.05
DVI_{15}	-.18**	.04	DVI_{50}	-.04	.01
R		.42****			.34***
	NO. PROPERTY DAMAGE				
	r	B		r	B
Central Business District vs. Other	.15**	.24***	CBD vs. OTHER	15**	.18*
Density	.29****	.36****	Density	.29****	.31****
VI_{15}	-.12*	-.22*	VI_{50}	.04	-.01
DVI_{15}	-.17**	-.03	DVI_{50}	-.06	-.06
R		.42****			.35***
	COMPOSITE SEVERITY				
	r	B		r	B
Central Business District vs. Other	.01	.06	CBD vs. OTHER	.01	.02
Density	-.10*	-.17	Density	-.10*	-.10
VI_{15}	.02	-.24*	VI_{50}	.03	-.06
DVI_{15}	.19***	.36***	DVI_{50}	.09	.14
R		.27			.15

$*p < .02$
$**p < .10$
$***p < .05$
$****p < .01$
$*****p < .001$

190.

Table 69.

COMPARISON OF 3-PREDICTOR EQUATIONS USING EITHER
VI_{15}, DVI_{15}, OR HFC_{15}

VI	r	B
Central Business District vs. Other	0.25***	0.33****
Density	0.20***	0.28***
VI_{15}	-0.10*	-0.23***
R		.40****
DVI		
Central Business District vs. Other	0.25***	0.28***
Density	0.20***	0.24***
DVI_{15}	.16**	-0.17*
R		0.38****
HFC		
Central Business District vs. Other	0.25***	0.25***
Density	0.20***	0.21**
HFC_{15}	0.20***	0.11
R		.35***

$*p < .20$
$**p < .10$
$***p < .05$
$****p < .01$
$*****p < .001$

191.

C.3 PREDICTOR EQUATIONS

The equations derived for predicting values of the accident history variables are as follows. For predicting Number of Accidents, two equations may be used.

A 3-predictor equation (without HFC_{15}) is:

(1)   2.02+3.07 (CBD vs. Other) +.0000897 (Density) - .258 (VI_{15}).

A 4-predictor equation:

(2)   1.52+2.67 (CBD vs. Other) + .0000855 (Density) + 1.26 (HFC_{15})
      - .415 (VI_{15})

For predicting Number of Vehicles Involved, a 3-predictor equation is:

(3)   3.97+6.50 (CBD vs. Other) + .000203 (Density) - .599 (VI_{15})

For predicting Number of Property Damage Accidents, a 3-predictor equation is:

(4)   1.67+2.07 (CBD vs. Other) + .000106 (Density) - .258 (VI_{15}).

Recognizing the high correlations among the three main criteria above, the above equations are somewhat redundant. With greater ease in gathering tallies on Number of Accidents, and the fact that variability in the other two criteria are contingent on the number of accidents, the choice should be made between Equations 1 and 2.

C.4 SITE LENGTH

As described in Section 3, all sites were of six block length. Therefore actual site length was not equal for all sites ($u=2978 \sigma=778$). Both number of intersecting streets and actual site lengths could not be controlled, hence it was felt that since intersections produce more conflicts and changes in the visual scene than length of road, it was preferred to control this variable instead of site length.

The correlation of site length with the Visibility, Demographic Socioeconomic, and accident variables were all low and site length was not employed in the previous regression analysis. After completion of the previous analyses we tested the effect of site length on both the multiple R and resulting predicting equations discussed previously. Multiple R in the 4 predictor case (Table 21 - Item 1) increased from .47 to .50 while in the 3 predictor case (Table 20 - Item 1) it increased from .40 to .43. The new resulting equations are:

4-predictor

    2.44+6.91 (CBD vs. Other) + .000154 (Density) + 2.93 (HFC15)

192.

4-predictor

$$2.44 + 6.91 \text{ (CBD vs. Other)} + .000154 \text{ (Density)} + 2.93 \text{ (HFC}_{15})$$
$$- .899 \text{ (VI}_{15})$$

3-predictor

$$3.61 + 7.85 \text{ (CBD vs. Other)} + .000164 \text{ (Density)} - .532 \text{ (VI}_{15})$$

These equations predict accident rate per 10,000 vehicle miles.

C.5 OTHER ANALYSES

A number of more minor analyses were performed on the data to investigate general trends. These include the effect of density, area type and visibility - treated separately - on accident history. Although neither of the following are significant (in comparison to the previous analyses) they are presented to illustrate general trends in the data.

Area Type

Figure 24 illustrates the effect of area type (CBD/OBD/RF) on accident rate. The conclusion, as expected, is that accidents tended to be more frequent and rates higher in CBD areas than in RF areas while OBD rates fell somewhat between the extremes. This can be most easily described by considering the definition of the 3 area types. CBD generates a high concentration of people and vehicles; RF a low concentration of both. The difference between the two is quite obvious. OBD sites tend to be a mix and are difficult to categorize (e.g., some could be RF, other CBD, others clearly OBD; the choice is sometimes vague).

However there was no correlation between area type and density so that the effect of CBD as an accident predictor is not duplicated by (or related to) population density. Simply stated, CBD sites generate traffic (both pedestrian and driver) while RF sites (with normally high population density) do not. The latter are the sources, but not concentrated ones (over time) as are CBD areas.

Population Density

Accident rates for high density areas tended to be much higher than for low density areas. However the accident histories for the median density sites both adjusted for volume and unadjusted were almost identical to the figures for the low density sites. This is illustrated in Figure 25. The cause of this mild discrepancy may be related to (1) the choice of boundary points for the medium density sites, which were selected primarily for equal cell size (27 per cell) and (2) the 17% figure for night traffic volume.

193.

Based on our original stratification into high, medium and low visibility as described in Section 3.3 and used in the statistical analyses, there was no clear pictorial relationship between visibility and accidents. Since the stratification was based primarily on pre-servation of equal cell counts (low vs medium vs high VI) it was decided to make a more realistic stratification of VI based on the results of Gallagher(35). Limits of 0-4.9; 5.0-9.99 and 10.0 or greater for low, medium and high visibility provided the results illustrated in Figure 26. It can easily be seen that both unadjusted and adjusted (by night-time volumes) accident frequencies tend to decrease with increasing VI.

Figure 24
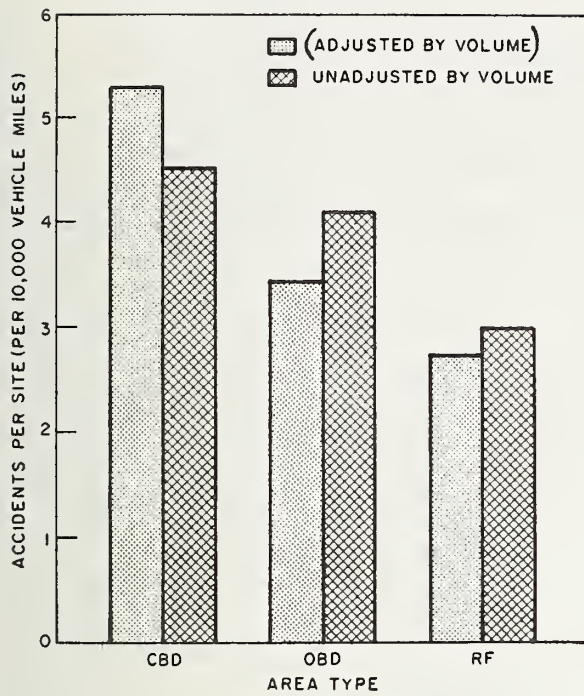
Area Type and Accidents

Figure 25
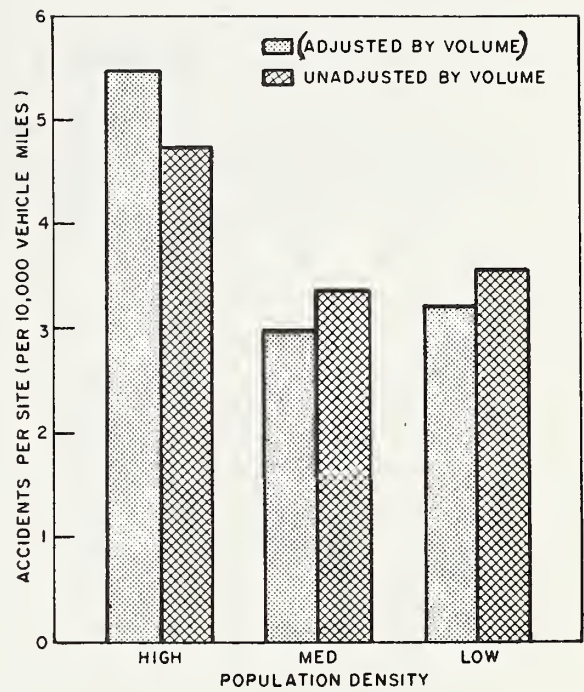
Population Density and Accidents

Figure 26.
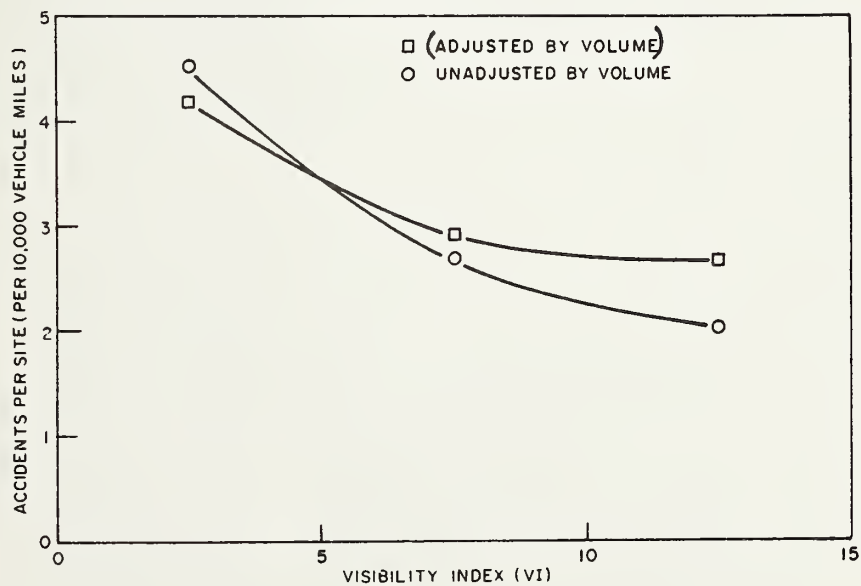
Visibility and Accidents

APPENDIX D - FIRL DATA BASE

This Appendix provides a summary table of the data base for the roadway and lighting conditions described in Section 7 of this report.

The complete data base is enclosed as Appendix A of the Design Guide.

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI 15	ENERGY USE (kwh/mi yr) 2 x10	INITIAL COSTS TOTAL ($/mi)	INITIAL COSTS ANNUAL ($/mi/yr)	ANNUAL COSTS ($/mi/yr) MAINTENANCE	ANNUAL COSTS ($/mi/yr) ENERGY	TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq. mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
60/400M/STG/100/35/11/M	23	13.4	1704	98040	10563	752	15228	26543	CBD	30000	20000	40	27208	1.03
60/400M/STG/100/40/11/M	24	13.8	1704	120960	13084	752	15228	29043	CBD	"	"	44	29476	1.02
60/400M/STG/100/45/11/M	25	13.8	1704	120960	13084	752	15228	29043	CBD	"	"	44	29476	1.02
60/400M/STG/150/45/11/M	30	10.7	1147	85383	9235	530	10749	20514	CBD	"	"	34	21995	1.07
60/400M/STG/200/45/11/M	35	7.8	852	64038	6927	398	8062	15387	CBD	"	"	24	15434	1.00
30/400M/SS/50/35/5/M	43	13.1	1720	96118	10356	737	14929	26022	CBD	"	"	40	27208	1.05
30/400M/SS/50/40/5/M	44	13.9	1720	118588	12827	737	14929	28493	CBD	"	"	44	29476	1.03
30/400M/SS/50/45/5/M	45	14.1	1720	118588	12827	737	14929	28493	CBD	"	"	44	29476	1.03
30/400M/SS/100/30/5/M	47	7.4	852	49020	5281	376	7614	13271	CBD	"	"	20	13592	1.02
30/400M/SS/100/35/5/M	48	9.1	852	49020	5281	376	7614	13271	CBD	"	"	27	18152	1.37
30/400M/SS/100/40/5/M	49	9.6	852	60480	6542	376	7614	14532	CBD	"	"	30	20410	1.40
30/400M/SS/100/45/5/M	50	9.8	852	60480	6542	376	7614	14532	CBD	"	"	30	20410	1.40
30/400M/SS/150/35/5/M	53	5.7	573	34602	3728	265	5374	9367	CBD	"	"	17	11334	1.21
30/400M/SS/150/40/5/M	54	6.5	573	42692	4618	265	5374	10257	CBD	"	"	20	13592	1.33
30/400M/SS/150/45/5/M	55	7.3	573	42692	4618	265	5374	10257	CBD	"	"	20	13592	1.33
30/400M/SS/200/40/5/M	59	4.4	426	32019	3463	199	4031	7693	CBD	"	"	10	7721	1.00
30/400M/SS/200/45/5/M	60	5.3	426	32019	3463	199	4031	7693	CBD	"	"	13	9076	1.18
30/400M/SS/250/45/5/M	65	3.9	344	27275	2950	170	3434	6554	CBD	"	"	10	9818	1.04
30/400M/OPP/100/30/5/M	67	12.8	1704	98040	10563	752	15228	26543	CBD	"	"	40	27208	1.03

197.

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI_{15}	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN-TENANCE	ENERGY							
30/400M/OPP/100/35/5/M	68	14.0	1704	98040	10563	752	15228	26543	CBD	30000	20000	44	29476	1.11
30/400M/OPP/100/40/5/M	69	14.7	1704	120960	13084	752	15228	29043	CBD	"	"	47	31740	1.09
30/400M/OPP/100/45/5/M	70	15.4	1704	120960	13084	752	15228	29043	CBD	"	"	47	31766	1.09
30/400M/OPP/150/45/5/M	75	10.8	1147	85383	9235	530	10749	20514	CBD	"	"	35	22220	1.08
30/400M/STG/100/25/5/M	86	15.2	1704	98040	10563	752	15228	26543	CBD	"	"	47	31753	1.20
30/400M/STG/100/30/5/M	87	16.3	1704	98040	10563	752	15228	26543	CBD	"	"	47	31822	1.20
30/400M/STG/100/35/5/M	88	16.3	1704	98040	10563	752	15228	26543	CBD	"	"	47	31822	1.20
30/400M/STG/100/40/5/M	89	16.3	1704	120960	13084	752	15228	29043	CBD	"	"	47	31822	1.10
30/400M/STG/100/45/5/M	90	16.2	1704	120960	13084	752	15228	29043	CBD	"	"	47	31816	1.10
30/400M/STG/150/30/5/M	92	11.0	1147	69205	7456	530	10749	18735	CBD	"	"	34	22674	1.21
30/400M/STG/150/35/5/M	93	12.3	1147	69205	7456	530	10749	18735	CBD	"	"	37	24942	1.33
30/400M/STG/150/40/5/M	94	13.0	1147	85383	9235	530	10749	20514	CBD	"	"	40	27208	1.33
30/400M/STG/150/45/5/M	95	13.2	1147	85383	9235	530	10749	20514	CBD	"	"	40	27208	1.33
30/400M/STG/200/35/5/M	98	9.0	852	51904	5592	398	8062	14052	CBD	"	"	27	18152	1.29
30/400M/STG/200/40/5/M	99	10.1	852	64038	6927	398	8062	15387	CBD	"	"	30	20410	1.33
30/400M/STG/200/45/5/M	100	10.7	852	64038	6927	398	8062	15387	CBD	"	"	34	22674	1.47
30/400M/STG/250/40/5/M	104	7.2	688	54550	5900	339	6867	13106	CBD	"	"	20	13592	1.04
30/400M/STG/250/45/5/M	105	8.3	688	54550	5900	339	6867	13106	CBD	"	"	24	15894	1.21
60/400H/OPP/100/25/11/M	106	16.0	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31803	1.09

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI 15	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN-TENANCE	ENERGY							
60/400H/OPP/100/30/11/M	107	17.7	1704	104589	11283	2548	15228	29059	CBD	30000	20000	47	31911	1.10
60/400H/OPP/100/35/11/M	108	17.7	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31911	1.10
60/400H/OPP/100/40/11/M	109	18.0	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31930	1.01
60/400H/OPP/100/45/11/M	110	18.0	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31930	1.01
60/400H/OPP/150/35/11/M	113	12.6	1147	73827	7964	1799	10749	20511	CBD	"	"	40	27208	1.33
60/400H/OPP/150/40/11/M	114	13.9	1147	90005	9744	1799	10749	22292	CBD	"	"	44	29476	1.32
60/400H/OPP/150/45/11/M	115	14.7	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31740	1.42
60/400H/OPP/200/40/11/M	119	8.5	852	67504	7308	1349	8062	16719	CBD	"	"	27	18152	1.09
60/400H/OPP/200/45/11/M	120	10.4	852	67504	7308	1349	8062	16719	CBD	"	"	30	20410	1.22
60/400H/STG/100/25/11/M	126	16.5	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31835	1.10
60/400H/STG/100/30/11/M	127	19.1	1704	104589	11283	2548	15228	29059	CBD	"	"	47	32000	1.10
60/400H/STG/100/35/11/M	128	18.7	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31975	1.10
60/400H/STG/100/40/11/M	129	18.2	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31943	1.01
60/400H/STG/100/45/11/M	130	18.5	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31962	1.01
60/400H/STG/150/30/11/M	132	13.1	1147	73827	7964	1799	10749	20511	CBD	"	"	40	27208	1.33
60/400H/STG/150/35/11/M	133	14.2	1147	73827	7964	1799	10749	20511	CBD	"	"	44	29476	1.44
60/400H/STG/150/40/11/M	134	15.0	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31740	1.42
60/400H/STG/150/45/11/M	135	15.5	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31772	1.43
60/400H/STG/200/30/11/M	137	8.2	852	55371	5973	1349	8062	15384	CBD	"	"	24	15894	1.03
60/400H/STG/200/35/11/M	138	10.9	852	55371	5973	1349	8062	15384	CBD	"	"	34	22674	1.47

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI₁₅	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOT.L COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN- TENANCE	ENERGY							
60/400H/ST6/200/40/11/M	139	12.5	852	67504	7308	1349	8062	16719	CBD	30000	20000	40	27208	1.63
60/400H/ST6/200/45/11/M	140	12.7	852	67504	7308	1349	8062	16719	CBD	"	"	40	27208	1.63
60/400H/ST6/250/35/11/M	143	8.1	688	47167	5089	1149	6867	13105	CBD	"	"	24	15894	1.21
60/400H/ST6/250/40/11/M	144	9.3	688	57504	6225	1149	6867	14241	CBD	"	"	27	18152	1.27
60/400H/ST6/250/45/11/M	145	10.8	688	57504	6225	1149	6867	14241	CBD	"	"	34	22674	1.59
30/400H/SS/50/25/5/M	146	23.2	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32260	1.32
30/400H/SS/50/30/5/M	147	22.6	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32222	1.13
30/400H/SS/50/35/5/M	148	24.4	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32336	1.14
30/400H/SS/50/40/5/M	149	24.2	1720	125008	13533	2498	14929	30960	CBD	"	"	48	32324	1.04
30/400H/SS/50/45/5/M	150	24.3	1720	125008	13533	2498	14929	30960	CBD	"	"	48	32330	1.04
30/400H/SS/100/25/5/M	151	13.0	852	52294	5642	1274	7614	14530	CBD	"	"	40	27208	1.87
30/400H/SS/100/30/5/M	152	15.0	852	52294	5642	1274	7614	14530	CBD	"	"	47	31740	2.18
30/400H/SS/100/35/5/M	153	16.6	852	52294	5642	1274	7614	14530	CBD	"	"	47	31842	2.19
30/400H/SS/100/40/5/M	154	16.9	852	63754	6902	1274	7614	15790	CBD	"	"	47	31860	2.02
30/400H/SS/100/45/5/M	155	17.1	852	63754	6902	1274	7614	15790	CBD	"	"	47	31873	2.02
30/400H/SS/150/25/5/M	156	6.1	573	36914	3982	899	5374	10255	CBD	"	"	17	11334	1.11
30/400H/SS/150/30/5/M	157	9.8	573	36914	3982	899	5374	10255	CBD	"	"	30	20410	1.99
30/400H/SS/150/35/5/M	158	11.5	573	36914	3982	899	5374	10255	CBD	"	"	37	24942	2.43
30/400H/SS/150/40/5/M	159	12.9	573	45003	4872	899	5374	11145	CBD	"	"	40	27208	2.44

200.

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI_{15}	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN- TENANCE	ENERGY							
30/400H/55/150/45/5/M	160	13.5	573	45003	4872	899	5374	11145	CBD	30000	20000	44	29476	2.64
30/400H/55/200/35/5/M	163	6.2	426	27685	2987	674	4031	7692	CBD	"	"	17	11334	1.47
30/400H/55/200/40/5/M	164	8.1	426	33752	3654	674	4031	8359	CBD	"	"	24	15894	1.90
30/400H/55/200/45/5/M	165	9.5	426	33752	3654	674	4031	8359	CBD	"	"	30	20410	2.44
30/400H/55/250/45/5/M	170	5.8	344	28752	3113	575	3434	7122	CBD	"	"	17	11334	1.59
30/400H/OPP/100/25/5/M	171	24.6	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32349	1.11
30/400H/OPP/100/30/5/M	172	25.6	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32413	1.12
30/400H/OPP/100/35/5/M	173	25.8	1704	98401	11283	2548	15228	29059	CBD	"	"	48	32426	1.16
30/400H/OPP/100/40/5/M	174	25.5	1704	127508	13804	2548	15228	31580	CBD	"	"	48	32407	1.03
30/400H/OPP/100/45/5/M	175	24.7	1704	127508	13804	2548	15228	31580	CBD	"	"	48	32356	1.02
30/400H/OPP/150/30/5/M	177	12.8	1147	73827	7994	1799	10749	20511	CBD	"	"	40	27208	1.32
30/400H/OPP/150/35/5/M	178	15.9	1147	73827	7964	1799	10749	20511	CBD	"	"	47	31797	1.55
30/400H/OPP/150/40/5/M	179	17.5	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31898	1.43
30/400H/OPP/150/45/5/M	180	17.9	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31924	1.43
30/400H/OPP/200/40/5/M	184	10.1	852	67504	7308	1349	8062	16719	CBD	"	"	30	20410	1.22
30/400H/OPP/200/45/5/M	185	12.4	852	67504	7308	1349	8062	16719	CBD	"	"	37	24942	1.49
30/400H/ST6/100/25/5/M	191	27.7	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32546	1.12
30/400H/ST6/100/30/5/M	192	28.7	1704	104589	11283	2548	15228	29059	CBD	"	"	49	32610	1.12
30/400H/ST6/100/35/5/M	193	27.2	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32514	1.12
30/400H/ST6/100/40/5/M	194	25.7	1704	127508	13804	2548	15288	31580	CBD	"	"	48	32419	1.03

201.

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI₁₅	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN-TENANCE	ENERGY							
30/400H/STG/100/45/5/M	195	24.7	1704	127508	13804	2548	15228	31586	CBD	30000	20000	48	32356	1.02
30/400H/STG/150/25/5/M	196	19.4	1147	73827	7964	1799	10749	20511	CBD	"	"	47	32019	1.56
30/400H/STG/150/30/5/M	197	20.2	1147	73827	7964	1799	10749	20511	CBD	"	"	48	32070	1.56
30/400H/STG/150/35/5/M	198	20.2	1147	73827	7964	1799	10749	20511	CBD	"	"	48	32070	1.56
30/400H/STG/150/40/5/M	199	20.6	1147	90005	9744	1799	10749	22292	CBD	"	"	48	32095	1.44
30/400H/STG/150/45/5/M	200	20.5	1147	90005	9744	1799	10749	22292	CBD	"	"	48	32089	1.44
30/400H/STG/200/25/5/M	201	12.9	852	55371	5973	1349	8062	15384	CBD	"	"	40	27208	1.77
30/400H/STG/200/30/5/M	202	15.9	852	55371	5973	1349	8062	15384	CBD	"	"	47	31797	2.07
30/400H/STG/200/35/5/M	203	16.7	852	55371	5973	1349	8062	15384	CBD	"	"	47	31848	2.07
30/400H/STG/200/40/5/M	204	16.8	852	67504	7308	1349	8062	16719	CBD	"	"	47	31854	1.91
30/400H/STG/200/45/5/M	205	17.0	852	67504	7308	1349	8062	16719	CBD	"	"	47	31867	1.91
30/400H/STG/250/25/5/M	206	7.3	688	47167	5089	1149	6867	13105	CBD	"	"	20	13592	1.03
30/400H/STG/250/30/5/M	207	11.9	889	47167	5089	1149	6867	13105	CBD	"	"	37	24942	1.90
30/400H/STG/250/35/5/M	208	13.8	688	47167	5089	1149	6867	13105	CBD	"	"	44	29476	2.25
30/400H/STG/250/40/5/M	209	14.7	688	57504	6225	1149	6867	14241	CBD	"	"	47	31740	2.23
30/400H/STG/250/45/5/M	210	15.3	688	57504	6225	1149	6867	14241	CBD	"	"	47	31740	2.23
60/150H/OPP/100/20/11/M	211	10.1	639	80491	8632	2548	5709	16889	CBD	"	"	30	20410	1.21
60/150H/OPP/100/25/11/M	212	11.4	639	104589	11283	2548	5709	19540	CBD	"	"	34	22674	1.16
60/150H/OPP/100/30/11/M	213	13.2	639	104589	11283	2548	5709	19540	CBD	"	"	40	27208	1.39

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI₁₅	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS TOTAL ($/mi)	INITIAL COSTS ANNUAL ($/mi/yr)	ANNUAL COSTS ($/mi/yr) MAINTENANCE	ANNUAL COSTS ($/mi/yr) ENERGY	TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
60/150H/OPP/100/35/11/M	214	13.5	639	104589	11283	2548	5709	19540	CBD	30000	20000	44	29476	1.51
60/150H/OPP/100/40/11/M	215	13.5	639	109387	13804	2548	5709	22061	CBD	"	"	44	29476	1.34
60/150H/OPP/150/30/11/M	218	8.0	430	73827	7965	1799	4030	13794	CBD	"	"	24	15894	1.15
60/150H/OPP/150/35/11/M	219	8.9	430	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/OPP/150/40/11/M	220	9.8	430	77214	9744	1799	4030	15573	CBD	"	"	30	20410	1.31
60/150H/OPP/200/35/11/M	224	6.2	319	56991	5973	1349	3022	10344	CBD	"	"	17	11334	1.10
60/150H/OPP/200/40/11/M	225	7.2	319	57911	7308	1349	3022	11679	CBD	"	"	20	13592	1.16
60/150H/STG/100/20/11/M	231	10.6	639	80491	8632	2548	5709	16889	CBD	"	"	34	22674	1.34
60/150H/STG/100/25/11/M	232	11.9	639	104589	11283	2548	5709	19540	CBD	"	"	37	24942	1.28
60/150H/STG/100/30/11/M	233	13.1	639	104589	11283	2548	5709	19540	CBD	"	"	40	27208	1.39
60/150H/STG/100/35/11/M	234	13.8	639	104589	11283	2548	5709	19540	CBD	"	"	44	29476	1.51
60/150H/STG/100/40/11/M	235	13.2	639	109387	13804	2548	5709	22061	CBD	"	"	40	27208	1.23
60/150H/STG/150/25/11/M	237	7.1	430	73827	7965	1799	4030	13794	CBD	"	"	20	13822	1.00
60/150H/STG/150/30/11/M	238	8.8	430	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/STG/150/35/11/M	239	9.2	430	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/STG/150/40/11/M	240	10.3	430	77214	9744	1799	4030	15573	CBD	"	"	30	20410	1.31
60/150H/STG/200/30/11/M	243	6.3	319	56991	5973	1349	3022	10344	CBD	"	"	17	11334	1.10
60/150H/STG/200/35/11/M	244	6.9	319	56991	5973	1349	3022	10344	CBD	"	"	20	13592	1.31
60/150H/STG/200/40/11/M	245	8.0	319	57911	7308	1349	3022	11679	CBD	"	"	24	15894	1.30
60/150H/STG/250/30/11/M	248	4.8	258	48547	5089	1149	2575	8813	CBD	"	"	13	9076	1.03

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI₁₅	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAINTENANCE	ENERGY							
60/150H/ST6/250/35/11/M	249	5.4	258	48547	5089	1149	2575	8813	CBD	30000	20000	13	9076	1.03
60/150H/ST6/250/40/11/M	250	6.8	258	49331	6225	1149	2575	9949	CBD	"	"	20	13592	1.37
30/150H/SS/50/20/5/M	251	9.1	644	78913	8463	2498	5597	16558	CBD			27	18152	1.10
30/150H/SS/50/25/5/M	252	11.4	644	102538	11062	2498	5597	19157	CBD	"	"	34	22674	1.18
30/150H/SS/50/30/5/M	253	13.0	644	102538	11062	2498	5597	19157	CBD	"	"	40	27208	1.42
30/150H/SS/50/35/5/M	254	13.2	644	102538	11062	2498	5597	19157	CBD	"	"	40	27208	1.42
30/150H/SS/50/40/5/M	255	13.6	644	107242	13533	2498	5597	21628	CBD	"	"	44	29476	1.36
30/150H/SS/100/20/5/M	256	6.3	319	40246	4316	1274	2854	8444	CBD	"	"	17	11334	1.34
30/150H/SS/100/25/5/M	257	8.6	319	52294	5642	1274	2854	9769	CBD	"	"	27	18152	1.86
30/150H/SS/100/30/5/M	258	10.7	319	52294	5642	1274	2854	9769	CBD	"	"	34	22674	2.32
30/150H/SS/100/35/5/M	259	11.0	319	52294	5642	1274	2854	9769	CBD	"	"	34	22674	2.32
30/150H/SS/100/40/5/M	260	10.6	319	54693	6902	1274	2854	11030	CBD	"	"	34	22674	2.06
30/150H/SS/150/20/5/M	261	4.1	215	28409	3047	899	2015	5961	CBD	"	"	10	6818	1.14
30/150H/SS/150/30/5/M	263	7.3	215	36914	3982	899	2015	6896	CBD	"	"	20	13592	1.97
30/150H/SS/150/35/5/M	264	6.4	215	36914	3982	899	2015	6896	CBD	"	"	17	11334	1.64
30/150H/SS/150/40/5/M	265	7.7	215	38607	4872	899	2015	7786	CBD	"	"	24	15894	2.04
30/150H/SS/200/30/5/M	268	4.8	160	27685	2987	674	1511	5172	CBD	"	"	13	9076	1.75
30/150H/SS/200/35/5/M	269	6.0	160	27685	2987	674	1511	5172	CBD	"	"	17	11334	2.19
30/150H/SS/200/40/5/M	270	6.4	160	28955	3653	674	1511	5838	CBD	"	"	17	11334	1.94

204.

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI_15	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN-TENANCE	ENERGY							
30/150H/55/250/30/5/M	273	3.6	129	23584	2544	575	1287	4406	CBD	30000	20000	10	6818	1.55
30/150H/55/250/35/5/M	274	3.7	129	23584	2544	575	1287	4406	CBD	"	"	10	6818	1.55
30/150H/55/250/40/5/M	275	4.4	129	24666	3113	575	1287	4975	CBD	"	"	10	6818	1.37
30/150H/OPP/100/20/5/M	276	13.7	639	80491	8632	2548	5709	16889	CBD	"	"	44	29476	1.75
30/150H/OPP/100/25/5/M	277	14.7	639	104589	11283	2548	5709	19540	CBD	"	"	47	31740	1.62
30/150H/OPP/100/30/5/M	278	16.0	639	104589	11283	2548	5709	19540	CBD	"	"	47	31803	1.63
30/150H/OPP/100/35/5/M	279	16.3	639	104589	11283	2548	5709	19540	CBD	"	"	47	31822	1.63
30/150H/OPP/100/40/5/M	280	15.6	639	109387	13804	2548	5709	22061	CBD	"	"	47	31778	1.44
30/150H/OPP/150/25/5/M	282	8.8	430	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
30/150H/OPP/150/30/5/M	283	10.4	430	73827	7965	1799	4030	13794	CBD	"	"	30	20410	1.48
30/150H/OPP/150/35/5/M	284	11.9	430	73827	7965	1799	4030	13794	CBD	"	"	37	24942	1.81
30/150H/OPP/150/40/5/M	285	13.2	430	77214	9744	1799	4030	15573	CBD	"	"	40	27208	1.75
30/150H/OPP/200/30/5/M	288	6.8	319	56991	5973	1349	3022	10344	CBD	"	"	20	13592	1.31
30/150H/OPP/200/35/5/M	289	8.3	319	56991	5973	1349	3022	10344	CBD	"	"	24	15894	1.54
30/150H/OPP/200/40/5/M	290	6.6	319	57911	7308	1349	3022	11679	CBD	"	"	20	13592	1.16
30/150H/OPP/250/30/5/M	293	5.3	258	48547	5089	1149	2575	8813	CBD	"	"	13	9076	1.03
30/150H/OPP/250/35/5/M	294	6.0	258	48547	5089	1149	2575	8813	CBD	"	"	17	11334	1.29
30/150H/OPP/250/40/5/M	295	5.9	258	49331	6225	1149	2575	9949	CBD	"	"	17	11334	1.14
30/150H/STG/100/20/5/M	296	13.6	639	80491	8632	2548	5709	16889	CBD	"	"	44	29476	1.75
30/150H/STG/100/25/5/M	297	16.4	639	104589	11283	2548	5709	19540	CBD	"	"	47	31829	1.63

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI$_{15}$	ENERGY USE (kwh/mi yr) x10^2	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN- TENANCE	ENERGY							
30|150H|STG|100|30|5|M	298	16.4	639	104589	11283	2548	5709	19540	CBD	30000	20000	47	31829	1.63
30|150H|STG|100|35|5|M	299	16.2	639	104589	11283	2548	5709	19540	CBD	"	"	47	31816	1.63
30|150H|STG|100|40|5|M	300	15.0	639	109387	13904	2548	5709	22061	CBD	"	"	47	31740	1.44
30|150H|STG|150|20|5|M	301	6.3	430	56817	6093	1799	4030	11922	CBD	"	"	17	12011	1.01
30|150H|STG|150|25|5|M	302	10.2	430	73827	7965	1799	4030	13794	CBD	"	"	30	20410	1.48
30|150H|STG|150|30|5|M	303	12.8	430	73827	7965	1799	4030	13794	CBD	"	"	40	27208	1.97
30|150H|STG|150|35|5|M	304	11.2	430	73827	7965	1799	4030	13794	CBD	"	"	34	24942	1.81
30|150H|STG|150|40|5|M	305	12.3	430	77214	9744	1799	4030	15573	CBD	"	"	37	24942	1.60
30|150H|STG|200|20|5|M	306	6.5	319	42613	4570	1349	3022	8941	CBD	"	"	20	13592	1.52
30|150H|STG|200|25|5|M	307	8.0	319	56991	5973	1349	3022	10344	CBD	"	"	24	15894	1.54
30|150H|STG|200|30|5|M	308	11.9	319	56991	5973	1349	3022	10344	CBD	"	"	37	24942	2.41
30|150H|STG|200|35|5|M	309	11.2	319	56991	5973	1349	3022	10344	CBD	"	"	34	22674	2.19
30|150H|STG|200|40|5|M	310	11.4	319	57911	7308	1349	3022	11679	CBD	"	"	34	22674	2.19
30|150H|STG|250|25|5|M	312	6.2	258	48547	5089	1149	2575	8813	CBD	"	"	17	11334	1.29
30|150H|STG|250|30|5|M	313	7.2	258	48547	5089	1149	2575	8813	CBD	"	"	20	13592	1.54
30|150H|STG|250|35|5|M	314	8.4	258	48547	5089	1149	2575	8813	CBD	"	"	24	15894	1.80
30|150H|STG|250|40|5|M	315	9.3	258	49331	6225	1149	2575	9914	CBD	"	"	27	18152	1.82
30|175M|55|50|30|5|M	358	10.1	753	96118	10356	737	6531	17624	CBD	"	"	30	20410	1.16
30|175M|55|50|35|5|M	359	10.7	753	96118	10356	737	6531	17624	CBD	"	"	34	22674	1.29

Table 70. Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI_{15}	ENERGY USE (kwh/mi yr) x10²	INITIAL COSTS		ANNUAL COSTS ($/mi/yr)		TOTAL COSTS ANNUAL ($/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS ($/mi/yr)	BENEFIT COST RATIO
				TOTAL ($/mi)	ANNUAL ($/mi/yr)	MAIN-TENANCE	ENERGY							
30/175M/SS/50/40/5/M	360	10.4	753	118588	12827	737	6531	20095	CBD	30000	20000	30	20410	1.02
30/175M/SS/100/30/5/M	363	6.4	373	49020	5282	376	3331	8989	CBD	"	"	17	11334	1.26
30/175M/SS/100/35/5/M	364	7.1	373	49020	5282	376	3331	8989	CBD	"	"	20	13592	1.51
30/175M/SS/100/40/5/M	365	7.1	373	60480	6542	376	3331	10249	CBD	"	"	20	13592	1.33
30/175M/SS/150/35/5/M	369	3.8	251	34602	3728	265	2351	6344	CBD	"	"	10	6366	1.00
30/175M/SS/150/40/5/M	370	4.5	251	42692	4618	265	2351	7234	CBD	"	"	13	9076	1.25
30/175M/STG/100/35/5/M	404	9.7	746	98040	10563	751	6662	17976	CBD	"	"	30	20410	1.14
30/175M/STG/100/40/5/M	405	10.1	746	120960	13084	751	6662	20497	CBD	"	"	30	20636	1.01
30/175M/STG/150/30/5/M	408	6.8	502	52195	5585	531	4702	12689	CBD	"	"	20	13140	1.04
30/175M/STG/150/35/5/M	409	7.6	502	69205	7456	531	4702	12689	CBD	"	"	24	15894	1.25
30/175M/STG/150/40/5/M	410	8.1	502	85383	9235	531	4702	14468	CBD	"	"	24	15894	1.10
30/175M/STG/200/30/5/M	413	5.2	373	51904	5592	398	3527	9517	CBD	"	"	13	9528	1.00
30/175M/STG/200/35/5/M	414	5.3	373	51904	5592	398	3527	9517	CBD	"	"	13	9753	1.02

FHWA

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